Manifestations and Student Awareness of Science Literacy Values in Different Teaching Contexts

by

Gregory Larry Henkelman

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Abstract

This qualitative exploratory study investigated how one teacher's view of science literacy was manifested in different classes. Using transcripts of semi-structured interviews and audio/video recordings of classroom and lab activities, one teacher's professed science literacy values were compared to the science literacy values evident in his teaching practice and in students' reports of their class experiences with him. Transcripts were coded using science literacy values developed in a framework used by Corrigan, Cooper, Keast, and King (2010) and Cooper and Corrigan (2011), with additional values added after a preliminary analysis of data from student and teacher interviews. Results suggest that while a teacher may clearly define and emphasize certain values of science literacy, different classroom settings and students may require different approaches to ensure those values are clearly understood. Findings from this study suggest that educators can develop greater autonomy and maintain passion for their profession by engaging in deep thought about their own science literacy values.

Preface

This thesis is an original work by Gregory Larry Henkelman. No part of this thesis has been previously published. The research project, of which this thesis is a part, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "Teacher Enactment of Science Literacy in Different Teaching Contexts," No. 00013290, May 31, 2010.

To my family, friends, mentors, colleagues and students.

Though the destination seems a speck far distant,

the momentum of a small step forward takes you there.

May you overcome all moments of inertia and hardship in your lives.

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AP® Advanced Placement
PISA Programme for International Student Assessment
OECD Organisation for Economic Co-operation and Development
CMEC Council of Ministers of Education, Canada
AAAS American Association for the Advancement of Science
IB® International Baccalaureate

CHAPTER 1: INTRODUCTION

Research Context

As a high school biology teacher for over a decade, I honed the requisite skills for delivering curricula, managing classrooms, and preparing students for success on external assessments – including provincial Diploma exams and international Advanced Placement (AP®) exams. As I became more comfortable in my role, I became increasingly interested in encouraging and pursuing questions about the philosophy and tentative, consensual acceptance of science with my students, their parents, and my colleagues. Students often asked why a lab did not work the way it was *supposed to* and parents and students often described to me their impressions of science (especially biology) as being a collection of facts: some parents even questioned how their students could be doing so poorly in a course based on memorization. As I thought about instances like these, I realized many students (and their parents) had not been given the tools to know how to deal with the potential for ambiguity in a science class and that, through either their own education or their perceptions of science, they had come to expect success in science learning to be a simple case of finding and reporting the "right" answer. My colleagues anecdotally reported similar instances and we often talked about how science meant more to us than the collection, dissemination, and repetition of facts. There was a discrepancy in what the nature of science meant for different people.

As I paid this thought more attention, it became increasingly clear to me that students were motivated to know what would be on the test and/or how to complete laboratory experiences "correctly" and volunteered little extra effort to assignments they deemed "worth-less" in the sense that they would not earn extra marks. Though I am not naïve and understand the drive to achieve top scores to secure university entrance and scholarship funding, this troubled me: Canadian students, and Albertan students in particular, achieve some of the top scores on assessments of science both nationally and internationally (OECD, 2010), yet some seemed uninspired to seek knowledge about science for its own sake. Their motivation to learn science was purely functional and had less to do with applying science to new situations and social concerns. When discussing these findings amongst my colleagues, one shared with me the article "*Ready or Not?*" from *Maclean's* magazine (Farran, 2008) which further piqued my interest and stimulated a return to graduate studies in education.

In the article, Farran reported that Programme for International Student Assessment (PISA) 2006 test results showed science education was alive and well in Canada, with Canada in third place after Finland and Hong Kong (it is worth noting that since then, 2009 PISA test results showed Canada falling to eighth place among 65 countries; Berry, 2011; the 2012 PISA test results showed Canada falling to twelfth place: http://www.oecd.org/pisa/keyfindings/pisa-2012-results.htm). But successful learning and retention is not only measured on standardized tests. In the same *Maclean's* article, concern was expressed about "high achieving" high school graduates having difficulty in university. Paul Cappon, CEO of the Canadian Council on Learning, was cited saying: "Parents are worried because they can't understand their children's mathematics homework and science homework, and that parental influence or fear is passed on to students" (p. 3). The same magazine issue later discussed a decision by the Faculty of Arts at the University of Alberta to accept Grade 12 students with *either* a Grade 12 math *or* science course, not both (see Faculty of Arts, 2013). As a science teacher, I considered the ramifications of this decision: could I motivate students for whom science was no longer required for post-secondary studies? Would it affect the ability of future Albertans to deal with an increasingly technical and science-dependent world? I wondered whether students were going to be able to achieve the loftier aspects of "science literacy" which are considered a key part of Alberta Programs of Study for high school science. An extension to this was to consider the value of science for all students: given the positive emphasis on reports of high performance on international assessments, was science literacy *really* that important to students and teachers? An article by Sadler and Zeidler (2009) shared some of my concerns. These authors pulled from ethnographic studies to support their argument that if science literacy is more than just rote memorization, assessment must reflect this and this had not been fully realized in the PISA tests. This article nicely summed up key findings of other articles while pointing out difficulties in: (a) defining science literacy, and (b) in assessing students' learning about "nature of science" concepts. As Sadler and Zeidler concluded:

"If educators, policy-makers, and researchers are genuinely interested in supporting the development of scientific literacy in all students, then they must consider data from testing, and from international projects like PISA, as just one element within the larger context of education" (p. 919).

In other words, educators and researchers in the field of science education must "bring it all together" to realize the goal of science literacy for all and somehow move away from an over-reliance on test-based teaching and learning to determine a student's "attainment" of science literacy.

"Bringing it all together" came to make my proposed study more personally relevant. I began to see that if the concept of science literacy was not considered by teachers themselves, the concept would remain as static words confined to pages of Programs of Study. Though teachers may bring science literacy to life for students by treating science as more than a collection of facts and skills used in a classroom or laboratory, I began to question whether all teachers, in all contexts of high school science, could and would do the same. My additional experiences with AP® students suggested these students prepared diligently for exams, but required extra motivation and direction to appreciate the value of science beyond the next assessment. I thus also questioned if students appreciate the value of science literacy in their lives if literacy "values" are not made explicit to them by teachers.

My experiences in parent-teacher interviews added another dimension to this concern and confirmed Paul Cappon's statements in the *Maclean's* article. Though parents frequently reported that learning science was important for their children's futures, they did not know how to become involved in their children's high school science courses. Parents reported to me a lack of knowledge about curriculum and course content. These parents appreciated my suggestion that they could help their children succeed at science by challenging them about social implications of what they were learning, and I provided parents with lists of potential Science, Technology, and Society (STS) issues from the Alberta Biology 20/30 Program of Studies to initiate conversations at home, but I felt something was still missing from the conversation. This suggested that parents, too, were unsure how to view science as anything more than "facts" to be mastered for an exam, stressing even more the importance of teachers in not simply reinforcing this narrow view of science, but strengthening and broadening it to match new ideas in science education.

The year before I began graduate studies, I had the opportunity to co-teach a course with a colleague. This experience proved to me that science is interpreted and taught differently by different teachers. Though we shared a classroom space, the same student group, similar knowledge of the Program of Studies and overall agreement on what the objectives of the course should be, differences in our approaches to making explicit connections to science literacy were obvious and reflected in students' reports of what they felt the course was about.

Research Purpose

As my insights were anecdotal and not carefully recorded, I realized a great opportunity to share my experiences through research had been compromised and potentially lost. At the same time, I realized that in telling this story, I could begin a dialogue to explain challenges and discoveries that have been part of my decade of practice amongst other science teachers. My concerns with science literacy beyond exam performance, parental disillusionment, and teacher differences culminated in my decision to attend to such concerns academically, but without forgetting that the main intention would be to share results to a broad community in a way that would be both theoretically and practically appealing.

Early readings for my graduate courses were used to catch up on literature in science education which, as a teacher, I had not been exposed to since completing my undergraduate degree in education. It quickly became apparent the positivist view of science that had permeated my Bachelor of Science "training" was facing increasing challenge by post-positivist and constructivist notions of sociocultural science. Though I still support post-positivist notions of reductionism, empirical observation, and theory verification for scientific inquiry into natural phenomena (Creswell, 2009) as being important in the practice of science, as a science teacher I could not ignore the broader discussions about the nature of science I was having with students, teaching colleagues, and those who practice and theorize about the nature of science on a grander scale. I began to "seek understanding of the world" (Creswell, 2009, p. 8) in which I lived and worked and realized my own training and experiences as a teacher would affect my interpretation of classroom situations. As I renewed my interest in the philosophy of science – including a re-reading of Kuhn (1970) and exposure to writings by Brush (1974), Halliday and Martin (1993), Kaiser (2005), Keller (1987), and Myers (1992) – I began to appreciate social and contextual aspects of science and embraced constructivism as a worldview to frame my current research. I realized how deeply I had assumed a "certified loyal gatekeeper and spokesperson for science" (Aikenhead, 2006, p. 63) role by preparing a few science students for post-secondary studies, ignoring the importance of science for *all* my students everyday life: I came to the optimistically troubling realization that if I was not teaching students about the complexity of the nature of science, they could not achieve full science literacy. After reading *The Myth of Scientific Literacy* by Morris Shamos (1995), I further questioned the purpose of science education and confirmed my hopes that teachers themselves could hold the answer to science literacy – not by defining it for students through direct teaching, but by sharing their science literacy values with their students and encouraging the students to consider the many ways science could be construed.

A social-constructivist reading of the Program of Studies which I thought I knew so well demonstrated my own lack of attention to the theoretical underpinnings of the Alberta science programs. There, plain to newly informed eyes, was the potential to clarify one's own values of "science literacy" in the curriculum by understanding science as a process: the potential to live the tension that Aoki (1991/2005) described as existing between the "curriculum-as-plan" and the "curriculum-as-lived." Here was an opportunity for elucidation of the ubiquitous interactions in the classroom that allow for local knowledge (Berliner, 2002) of science that could be made, at least, *more* relevant to *more* students and build their personal motivations for appreciating science. I realized such an attempt would require consideration of three aspects of curriculum (Aikenhead, 2006): intended (curriculum policy), taught (resources and teacher orientation), and learned (intended or unintended student knowledge acquisition). To this end, I sought a research paradigm that would allow me to address all three curricular aspects by using the focal point of science literacy in a way that I could share and discuss my findings with teaching colleagues and fellow researchers. Thus, I chose to study the professed and manifested science literacy values of a teacher and their learning consequences for his students.

Science Literacy and Nature of Science

Part of my exploration of science teaching necessitated a consideration of how science literacy and nature of science might correspond to my questions. There is overlap between the concepts of nature of science and science literacy, partly because both have been used so often in the literature that their meanings have become difficult to pin down and separate as distinct ideas. As such, a discussion of both terms is in order to demonstrate why science literacy, and not understanding of nature of science, is the focus of my research.

Nature of science can be defined as values and assumptions inherent to scientific knowledge and its development. Lederman and Lederman (2004) focus on seven aspects of nature of science that they feel are generally agreed upon as being important for K – 12 education. These seven aspects are: (a) the difference between observation and inference, (b) the distinction between scientific laws and theories, (c) science knowledge is based on and/or derived from observations of the natural world, (d) scientific knowledge involves human imagination and creativity, (e) scientific knowledge is at least partially subjective, (f) science is culturally and socially embedded, and (g) scientific knowledge is subject to change.

Many of the parent and student conversations I have mentioned focused on a narrow view of the nature of science: what "facts" students should learn and how should they learn these facts, but not what should they *do* with science knowledge and thinking skills, other than earn high marks allowing them continue with post-secondary science studies and perhaps become practicing technicians of science. These conversations demonstrate a partial understanding of the first three aspects from Lederman and Lederman (2004) mentioned above (that is, that science involves a certain way of gathering and legitimizing science knowledge), but either ignore or minimize the four other aspects that demonstrate the tentative and cultural aspects of science.

Science literacy, then, can be seen as at least partially relating to the *development* of broader views of nature of science. Even by focusing only on nature of science aspects, educators can work to develop greater science literacy in their students

(Mahatoo, 2012; Holbrook & Rannikmae, 2009). However, science literacy can also move beyond building nature of science understanding, expanding the appreciation of science to realms that are not scientific per se. Notions of "informed citizens" and how science is valued differently by different groups (for example, scientist practitioners versus science educators) make the idea of how to use scientific knowledge one of "literacy" beyond reading, writing, and practicing science, which for many of the students and parents I met "was" the nature of science. This notion was explored by Mahatoo (2012) in a study on how accepting a broader and more contemporary view of nature of science could increase students' overall motivation to learn science, making science literacy an *attitudinal value* with far-reaching societal benefits. It is interesting to note that students involved in the initiatives described by Mahatoo showed not only a deeper commitment to learning science, but also higher test scores on international assessments such as the PISA test. This suggested to me that science literacy *includes* an evaluation of the importance of the nature of science by students for themselves and their world: what students deem of value can impact their motivation to achieve.

The importance of appreciating nature of science in a societal context was also explored by Holbrook and Rannikmae (2009), who suggest that science literacy must include not only a deeper appreciation for the complexity of nature of science, but also personal learning attributes, including attitudes and social values. If we are to understand that science literacy should include attitudes and beliefs about the *use* of nature of science in our everyday lives, then an exploration of science literacy should include a discussion about what it is in science education (including a deeper appreciation of the nature of science) that one values.

Another important consideration for teachers is that the Alberta Programs of Study use the term "science literacy" in three different ways. This can be found in the following statement found on the first page of the *Biology 20/30 Program of Study*:

> To become scientifically literate, students need to develop knowledge of science and its relationship to technologies and society. They also need to develop the broad-based skills required to identify and analyze problems; to explore and test solutions; and to seek, interpret and evaluate information. To ensure relevance to students as well as to societal needs, a science program must present science in a meaningful context —providing opportunities for students to explore the process of science, its applications and implications, and to examine related technological problems and issues. By doing so, students become aware of the role of science in responding to social and cultural change and in meeting needs for a sustainable environment, economy and society. The secondary science program is guided by the vision that all students, regardless of gender or cultural background, are given the opportunity to develop scientific literacy. The goal of scientific literacy is to develop in students the knowledge, skills and attitudes that they need to solve problems and make decisions and, at the same time, to help students become lifelong learners who maintain their sense of wonder about the world around them. Diverse learning experiences within the science program provide students with opportunities to explore, analyze and appreciate the interrelationships among science, technology, society and the environment and to develop understandings that will affect their personal lives, their careers, and their futures.
>
> (Alberta Education, 2009a, p. 1)

First, the statement calls for the need for students to "become" scientifically literate by developing knowledge of science, technology, and society. This suggests science literacy is a *necessary end-goal* that characterizes a "good" science student. In this use, "scientifically literate" could be akin to "responsible and informed citizen": This also suggests some students are not already scientifically literate and need to become so in order to fully contribute to society. Second, teachers are admonished to give students opportunities to “develop” scientific literacy, suggesting literacy attainment is something that can progress along a continuum, not just emerge as an end-goal, within students. This suggests scientific literacy “progress” of students should be monitored in some way, but also muddies the initial use of the term: Should teachers *ensure* students become scientifically literate or should they *promote* scientific literacy? The third use of the term – “the goal of scientific literacy” – turns scientific literacy into a tool, a teaching method or “program” which prioritizes certain knowledge, skills, and attitudes to solve problems and help students make decisions about the world around them. In summary, all Alberta Grade 7 to 12 science teachers must cope with simultaneous views of science literacy as *product*, *progression*, and *program*. Given that very little attention may be paid to the notion of science literacy in many pre-service teaching programs, this becomes a very complex issue for new and experienced teachers alike.

Defining Science Literacy

After considering the Alberta science literacy statement and a review of the literature (Chapter 2), it can be argued that “science literacy” has no set definition. As such, science literacy becomes a personalized construct, based on one’s own experiences and exploration of the idea. This ambiguity is both promising and problematic: if science literacy is defined too narrowly (for example, the ability to memorize facts or be successful in competing for positions in science-related fields), much of the population will deem it to be of little value to their lives (Aikenhead, 2006). Defined too broadly, science literacy becomes seemingly unattainable and loses value for educators who are unsure how to assess if it has actually been achieved (Shamos, 1995).

My own definition of science literacy has evolved throughout the research process, drawing on a review of the literature, reflection about my own laboratory and classroom experiences, and a consideration of the value of science to those who will and will not pursue a career in science. At first, I saw science literacy as being very practical, fitting very well within two of Bybee's (1995) domains of science literacy: functional and conceptual/procedural. In these domains, students could be considered to have achieved science literacy if they were able to clearly communicate – using the proper scientific vocabulary – what they had learned in class, and apply that knowledge to new situations, using the scientific method to define, clarify, and solve problems through the application of theories and empirical investigations. This definition served me well as a science student and practitioner, and was fairly easy to incorporate within the science classroom. Science "facts" were easily tested on worksheets, quizzes, and exams. The skill with which students could follow science procedures in a laboratory was easily observed. However, there were other aspects of science literacy that began to attract my attention as a science teacher which seemed to be missing or given less attention in the classroom and which would be considered as part of Bybee's (1995) "multidimensional" aspect of science literacy. Based on my own teaching experiences, I have come to believe that science literacy needs to include an appreciation that science is a creative human process, with a rich history of trial and error leading to our current – but tentative – consensus of how to explain our observations of the physical world.

Research Question

I began to contemplate how science literacy might be used to open or continue discussions about science *as an idea*, personally interpreted and valued, in Alberta classrooms so that teachers and students could more fully “live” the Program of Studies in their teaching and learning of science. My concern involved not only AP® science teachers and students (who often value continuation of science education at the post-secondary level), but also students for whom formal science education would end with the completion of a minimum of two science courses – perhaps as early as the end of their first year of high school – so I added the component of applying science literacy values in different teaching contexts. Thus, my research question took shape: To what extent are a teacher’s professed values of science literacy communicated to and understood by students in different classroom contexts?

Significance of the Study

This study is significant in three ways. First, by asking teachers and students what their own views and/or values of science literacy are, the participants become part of the exploration of this concept. Teachers, students, and researchers will be able to use findings from this exploration to ground ideas of science literacy in actual classroom context. Second, through ongoing discussions, participants themselves will be able to consider their own work in teaching and learning, in the process gaining greater autonomy over how the curriculum can be taught to honour and include, but also challenge, their own values of science literacy. Third, if the science literacy statement in the Alberta programs of study is not being considered in the classroom, perhaps my study has value as a resource for professional development and even pre-service teacher training so that more students can find “value” in our science classrooms.

CHAPTER 2: REVIEW OF LITERATURE

Introduction

This literature review will provide the reader with a short history of the notion of science literacy, followed by a description of how science literacy is presented as an overarching theme in Alberta secondary science courses. As secondary science in Alberta consists of many disciplines and streams, studies involving diverse teaching contexts are then discussed to demonstrate how values of science literacy are constructed, not simply delivered. As construction of meaning requires both delivery and acceptance of values, the literature review will then support the need for a qualitative, interpretive inquiry study of how teachers make known their own science literacy values in classrooms, extending and filling in gaps of previous research by including the students' acceptance of these values. It will also outline the analytical framework that will be used to interpret the collected data and explain how this framework allows participants to engage in the research as fellow inquirers.

Science Literacy

Though Hurd (1998) suggested modern ideas of science literacy designed to benefit society could be traced as far back as 1620 and Francis Bacon's *Novum Organum*, he also made clear that science literacy has been an educational consideration in the United States for more than 200 years, dating back at least to Thomas Jefferson, who enlisted the help of DuPont de Nemours to ensure that citizens were trained to *use* science wisely and in a formalized way. Oliver, et al. (2001) also demonstrated that the current debate about science literacy is rooted in older debates of the purpose of science in general. The current manifestation of using science literacy as an educational rallying cry can be seen in the 1956 *Science Manpower Project* at Columbia University, which exploited American concerns about the USSR's launch of Sputnik in calling for a national effort to address widespread "scientific illiteracy" (Roberts, 2007) amongst politicians and the general public. More recently, the 1993 American Association for the Advancement of Science (AAAS)'s "Project 2061" *Benchmarks for Science Literacy* program influenced the 1996 *National Science Education Standards* to call for an educational reform focused on science literacy for all Americans (Nelson, 1997). Impey, Buxner, Antonellis, Johnson, and King (2011) have recently completed a 20-year study relating to Project 2061 and re-affirming the importance of science literacy, calling science and technology the "…'amniotic fluid' around all who live in the industrialized world and, increasingly, in any part of the world."

Science literacy concerns extend beyond American borders. In a recent edition of the International Journal of Environmental and Science Education (Bahar, 2009), researchers from Australia, New Zealand, Germany, Lebanon, South Africa, and Thailand contextualized the concept of science literacy in their own countries. Choi, Lee, Shin, Kim, and Krajcik (2011) discussed the importance of establishing a new vision of science literacy in South Korea. Mahatoo (2012) expressed the value of increasing science literacy in Trinidad and Tobago. The Council of Ministers of Education, Canada (CMEC) stressed the importance of science literacy, defining it as "an evolving combination of the science-related attitudes, skills, and knowledge [that] students need to develop inquiry, problem-solving, and decision-making abilities, to become lifelong learners, and to maintain a sense of wonder about the world around them" (CMEC, 1997, section 2).

Several articles written over the past 15 years discuss the history and implications of both the Project 2061 and CMEC standards and what they mean to North American educators. Six articles are summarized in this literature review (Bybee, 1995; DeBoer, 2000; Eisenhart, Finkel, & Marion, 1996; Hurd, 1998; Koballa, Kemp, & Evans, 1997; Laugksch, 2000) to place my own study in the context of science education research.

Rodger Bybee (1995) differentiated amongst forms of science literacy (functional, focused on vocabulary; conceptual/procedural, focused on science as a different way of knowing; and multidimensional, which adds consideration of historical, technological, and personal aspects of science in society). Though Bybee pointed out that functional literacy is not enough to claim one is scientifically literate, he did not suggest doing away with it altogether. Instead, Bybee suggested the *National Science Education Standards* and the *Benchmarks for Science Literacy* in the United States presented a "balance of functional, conceptual, procedural, and multidimensional scientific literacy" (p. 31) which clarified the content and dimensions of achieving science literacy for all students. Bybee's "balance" agrees with Canadian researchers Norris and Phillips (2003), who suggested that science literacy should be considered in both its fundamental sense (the ability to use science) and its derived sense (the ability to learn science).

Eisenhart et al. (1996) focused on the same documents as Bybee. Though they saw these efforts as improvements over older forms of science education which stressed fact acquisition through memorization, Eisenhart et al. argued these documents wrongly "assume that producing citizens who can use science responsibly and including more people in science will naturally *follow from* teaching a clearly defined set of scientific principles" (p. 268). Eisenhart et al. thus contradict Bybee in saying the documents are too *implicit* and do not deal with issues such as discourse inequities between teachers and students.

Mention of discourse was prophetic given many studies of the past 12 years have focused on discourse using socio-political theoretical perspectives (cf. Barton & Tan, 2009; Brown & Ryoo, 2008; Brown, Reveles, & Kelly, 2005; Reveles, Cordova, & Kelly, 2004; Shepardson & Britsch, 2006; Wallace, 2004). These studies used ethnographies and interviews to focus on students' use of language and discussed the role of science discourse in forming students' identities in the classroom. These studies are mentioned because of their influence in exploring and elucidating the important role that student perceptions of science have on their own science literacy acquisition. These studies did not, however, make explicit what happens (if anything) to *teachers'* perceptions in the midst of discourse relationships. This misses the importance of the sociocultural impact of discourse on the teacher to inform his or her future practice.

DeBoer (2000) discussed history of science literacy in North America and demonstrated how 1970s science literacy proposals opened up debates about how to teach science. According to DeBoer "what made these proposals especially controversial was the suggestion that social issues, and not disciplinary content, should be used as organizing themes of science teaching" (p. 588). This debate about the importance of content versus nature of science remains relevant today due to the importance some attribute to achievement on international standardized assessments of science literacy. Though DeBoer admitted that no attempts to define science literacy have been successful, he concluded "scientific literacy has usually implied a broad and functional understanding of science for general education purposes and not preparation for specific scientific and technical careers" (p. 594). The relevance of this statement for my study is supported by its use in Alberta Education's (2007a) *Elementary Science Literature Review*. The use of this statement in a primary school document demonstrates the broad acceptance of science literacy and further attests to the idea that science literacy is a goal which can apply to *all* students, not just those for whom post-secondary science education is a goal. DeBoer agrees saying "not everyone will develop the same knowledge and skill, but feeling that one can continue to learn and participate are key elements to life in a democratic society" (p. 598).

Paul DeHart Hurd (1998), one of the first researchers in the United States to actually use the term *science literacy* in the 1950s, noted increasing emphases on teaching science to citizens who will not become scientists. With this in mind, Hurd developed a list of characteristics of science literacy rather than proposing a narrow definition. According to Hurd, these characteristics "are not taught directly but are embedded in a lived curriculum where students are engaged in resolving problems, making investigations, or developing projects" (p. 414). Practical science, according to Hurd, should be viewed as "exercises in citizenship" (p. 414) that stimulate students' higher order thinking skills. The focus is on students, but the implication is that teachers need to consider characteristics of science literacy when planning lessons.

Science literacy may belong to a "class of terms like *liberty*, *justice*, and *happiness*, that we assume to contain simple and desirable qualities but that under closer examination become vastly more complex and elusive" (Laugksch, 2000, p. 73). Laugksch adds that interpretation of science literacy needs to be considered in relation to "interest groups" (p. 74). As such, Laugksch was not as concerned with finding a single definition of the term as he was with suggesting that researchers "spell out their position(s) with respect to relevant factors of scientific literacy when discussing such a concept" (p. 90).

Lack of consensus about science literacy draws to mind Berliner's (2002) discussion of "decade by findings" interactions (p. 20) in which social and environmental changes over time cause conceptions of educational policies (like "science literacy for all") to be altered to the point that they become invalid to educators living within a different cultural paradigm. Hodson (2005) agrees, saying curriculum proposals utilizing science literacy as a framework are "a product of their time and place: they do not easily cross national or cultural boundaries" (para. 8). Shamos (1995) also points out many of the dangers arising from ad hoc curriculum changes and crash course programs focused on making every student a scientist ("universal literacy") in that such efforts are doomed to fail due to the fact that literacy cannot be clearly defined universally.

This does not mean consensus cannot develop, however. For example, in Bybee (1995), DeBoer (2000), Eisenhart et al. (1996), Hurd (1998), Koballa et al. (1997), and Laugksch (2000), we see a common thread in that they do not call for teachers to teach science in a traditional way, preparing a *minority* of students in science classrooms for post-secondary science courses – what Aikenhead (2006) and Shamos (1995) call "the pipeline." On the contrary, they call for an emphasis on teaching science to the *majority* of students in classrooms: those who may never take science after junior or senior high school but who still live in a world dependent on science. They point out the crucial consideration teachers must give to all types of students in enabling scientific literacy. This involves recognizing social and cultural construction of science knowledge by using students' and teachers' own experiences and values (Corrigan, Cooper, Keast, & King, 2010; Cooper & Corrigan, 2011; Fensham, 2004) to move science literacy from its *implied* development in students into discussion of *explicit* recognition and use of one's own interpretations of science literacy. These discussions can inform teaching practice and allow teachers to share their experiences with others.

Albertan Perspectives on Science Literacy Outcomes

As mentioned previously, science literacy and the role it is meant to play in preparing even primary school students for "life in a rapidly changing world" (Alberta Education, 1996) permeates Alberta Education's Science Programs of Study. However, due to time and resource constraints, my study was limited to focus on how science literacy values appear in high school secondary science classes only, which themselves provide a great deal of variation in learners and learner expectations. One goal is consistent in these courses, however: "The senior high science programs will help all students attain the scientific awareness needed to function as effective members of society…the expected student knowledge, skills, and attitudes are approached from a common philosophical position in each science course" (Alberta Education, 2007c, para. 1). The science literacy statement found at the beginning of the *Biology 20/30 Program of Studies* (Alberta Education, 2009a, p. 1), which was reproduced in full in Chapter 1 of this thesis (page 10), is identical to that found on the *Chemistry* and *Physics* Programs of Study (Alberta Education, 2009b, 2009c) and Science 7-9, 10, and 14/24 documents are very near identical (see Alberta Education, 2003, 2005, 2007b, 2009d). They differ in a few words, but certainly call for emphasis on science literacy as a major goal of science education in Alberta. Emphasis on science literacy at all levels of science fits well with

Koballa et al. (1997), who see science literacy as a spectrum. Their paper is unique because they make explicit the role of teachers in applying philosophy of science differently in different classes: "Teachers can…place themselves and their students at levels appropriate for their understanding….along a science literacy continuum" (p. 28). Koballa et al.'s mention of teacher consideration of their own levels of literacy is particularly relevant for my study and demonstrates the importance of teacher discussions surrounding this statement even before they begin sharing the notion with students.

One concern with commonality of statement across grades and programs is the potential for teachers to misinterpret the idea of a common *philosophical position* on science literacy for a suggested *common methodology* to teach science literacy. This could prove detrimental to diverse learners. On the other hand, with so many ways to interpret "science literacy," teachers may find themselves not even knowing where to begin, which could prevent the idea of science literacy from being shared in any conscious way at all. Allowing teachers multiple opportunities to share their own science literacy values may promote more complex discussions of what it means to be literate in science, thus clarifying the connections amongst common science teaching strategies, specific learning contexts, and science application beyond classrooms.

Diverse Teaching Contexts

In secondary schools (high schools), students decide how far they wish to pursue science after graduation and – in a practical sense – decide what level or type of science literacy *they* wish to attain by choosing which science courses, or streams, to enroll in. The words "track" and "stream" are used interchangeably in this section as authors of the reviewed literature tend to favor one term or the other. Whether differential placement or "streaming" of students is justified is not discussed here. Instead, focus is limited to considering how, if at all, teachers alter their practice with different groupings of students towards attainment of science literacy.

Alberta offers several streams of science in its formal provincial curricula. The 10/20/30 courses are streams followed by students who generally pursue post-secondary education, though not necessarily in science programs, after graduation. The Science 14/24 program (Alberta Education, 2003) and the Knowledge and Employability Skills courses (Alberta Education, 2006), are taken by students who generally do not pursue post-secondary science. Many schools in Alberta also offer Advanced Placement (AP®) or International Baccalaureate (IB®) courses that enable students to earn college credit while still in high school. These science courses are meant to further challenge and prepare students for post-secondary science by teaching content, concepts and even laboratory skills that extend beyond the Alberta Programs of Study.

Why Distinct Groups are Important in Science Literacy Discussions

Given that multiple streams do exist, should this affect the way a teacher delivers the concept of science literacy to his or her students? How important is science literacy as a concept for regular high school students in Alberta preparing for a multiple choice Diploma exam that may affect university entrance? Are the needs of AP® students different? What about students in Knowledge and Employability courses who will likely never choose science careers?

According to de Brabander (2000), "there is a growing awareness of the differences between different contexts where teaching and learning takes place and of the necessity to incorporate the consequences of these differences in reform strategies and policies" (p. 1028). I would argue context goes beyond "reform strategies and policies" to include everyday teaching decisions, or curriculum delivery. For example, Randy Yerrick (2000) suggests the "'just-the-basics' mentality and compromising science by watering down the curriculum for lower track students continue to perpetuate a learned helplessness for these students regarding scientific knowledge" (p. 831). Yerrick adds that with proper scaffolding of inquiry, his lower track students "began to acquire a more sociolinguistic treatment of scientific concepts and arguments…[which promoted] a sense of community…[and] authentic engagement" (p. 830). Despite this success, Yerrick calls for more work to be done, particularly with respect to classroom context, "to determine what precursors or conditions must exist to regularly invoke these shifts and how such inroads can become a part of teacher practice" (p. 831). Thus, consideration of different streams as distinct groups can facilitate more personal and meaningful values of science literacy for students and their teachers.

Science Literacy as a Classroom Construct

Drawing on Henry Giroux (1992), Glen Aikenhead recognizes "inherent border crossings between students' life-world subcultures and the subculture of science…[and that] we need to develop curriculum and instruction with these border crossings explicitly in mind, before the science curriculum can be accessible to most students" (Aikenhead, 1996, p. 2). Aikenhead (2006) makes connections to the work of Brown (2004) to further justify this point. If Giroux, Aikenhead, and Brown's premises are extended to consider streams and grade levels as distinct cultures, teachers can act as local tour guides, taking students through varying landscapes of curricular content, translating and making students more literate in science by choosing appropriate teaching strategies for each particular group. Teachers' subcultures also enter the classroom culture (as discussed by Barnett and Hodson, 2001) and require consideration. Of course, this necessitates acceptance of the *existence* of "subcultures" and "cultures," which Aikenhead (2006) suggests is not as common amongst science teachers as it could be.

If a teacher *does* accept the notion that multiple influences affect constructed classroom cultures, he or she may also see a need to utilize diverse teaching strategies, selected carefully, to incorporate the subcultures within these cultures. Zohar and Aharon-Kravetsky's (2005) study of groups of students designated "low academic aptitude and achievement (LA) students" or "high academic aptitude and achievement (HA) students" (p. 831) finds cognitive conflict approaches to teaching science may not work well with LA students. Though some teachers may see this as a call to avoid cognitive conflict as a scientific literacy goal in lower streams, Zohar and Aharon-Kravetsky disagree saying that "differences between teaching students with low versus high academic achievements should center on adjustment of the pedagogies used for each group of students rather than on the goals of teaching" (p. 849). This reinforces the importance of teachers' roles in classrooms as active implementers and modifiers of curricula to address commonly-applied goals like science literacy. It also points out the need for deeper consideration of how teachers frame lessons for different groups of students.

At the other end of the academic spectrum are studies that consider perceptions of AP® or IB® classes. As I am more familiar with the AP® curricula, I have limited my discussion in this study to AP® courses rather than the IB® equivalents. As AP® curricula are mainly developed in the United States, it would make sense that they would be affected by American conceptions of what science literacy should look like. Indeed, recent changes in AP® science curricula reflect a more holistic approach to science literacy. Students are required to use inquiry to understand the interconnectedness of the disciplines through the use of "Big Ideas" of science rather than focusing on mastering the content that traditionally defined them (The College Board, 2014a,b,c & d). However, new ideas in science education do not necessarily provoke a similar desire to move away from traditional direct, content-heavy teaching and learning approaches that many students find comfortable and "safe" for earning high test scores. As Miller (2006) found, implementation of novel approaches to science (in his study, interdisciplinary concepts) can be resisted by AP® students who perceive "nature of science" as requiring content mastery and high marks on an exam and/or correct results on a lab activity. Rascoe and Atwater (2005) examined perceptions held by African-American students in an AP® class to determine what impact preconceptions have on their academic achievement. Rascoe and Atwater found that "when science teachers validate themselves and validate their Black male students' self-perceptions of academic ability, they have also set the stage for motivating these students" (p. 908). Despite the *implied* importance of teachers in their study, it is important that Rascoe and Atwater note "one limitation of this study was the absence of perspectives from the participants' science teachers" (p. 909). Their research is conducted entirely outside of the classroom itself, meaning subtle nuances of student-teacher interactions may be missing. Despite these limitations, the researchers still report that a teacher's ability to clearly deliver content of the course is considered essential by high achieving students to encourage them to always perform to the best of their abilities. But is high performance on assessments the only indicator of science literacy?

Teacher Pre-conceptions

In de Brabander's (2000) study, the focus moved away from students' perceptions of science and towards teachers' preconceptions of *knowledge*, in different subject areas and in different streams in each of those subject areas. This moves his work out of the realm of "research on teaching and the teacher…directed toward the development of generic theories" (p. 1028) and into the realm of the "context-dependent" (p. 1028) nature of teaching. This is different than the discourse methods previously discussed because de Brabander is specifically looking at *teachers'* views of the content they teach, particularly with respect to whether content they deliver is perceived by the teachers as being every day, or "soft" (p. 1039), knowledge or academic, testable, objective, and established "hard" (p. 1040) knowledge. Another interesting aspect of de Brabander's work is the potential of "generalization bias" (p. 1028) that teachers of the same subjects may share. Pointing out that "different subject areas have different status" (p. 1029) and that different teacher subcultures can arise in a "system of tracking that offers vocational, general secondary, and academic (pre-university) education" (p. 1029), de Brabander considers many variables in his analysis that bear careful consideration.

One advantage of de Brabander's (2000) study is his recognition that "teachers of secondary education frequently have classes at more than one track level…Therefore, differences in knowledge definition may exist not only *between* but also *within* teachers" (p. 1032). Though de Brabander focuses on definitions of knowledge, it is interesting to consider whether the same differences would be seen in teachers' manifestations of science literacy values as they move from grade to grade and/or track to track in high school science courses. In the end, de Brabander finds that, though teachers of different subjects view the knowledge *they* teach as different than the knowledge taught by *other* teachers, "individual teachers in general are not aware of differences in knowledge they teach at different track levels" (p. 1044). Do Alberta teachers follow the same pattern, not recognizing they may teach different "types" of science literacy to students in different tracks or streams of science?

Manifestations of Science Literacy Values

Values of Distinct Groups

The stage is set: The actors now begin the play. In education research, teachers and students must be placed in the spotlight. Assuming that one community of students and teachers, in a specific grade, stream, and even class section, will value science differently than other communities of students and teachers in different settings, a sociocultural framework could be used to view science literacy as a co-constructed concept in each class "culture," rather than a clearly defined goal to be achieved. If this is the case, universality of science (and science literacy) cannot be taken as a fundamental theoretical frame upon which to base teaching of science, unless a teacher wishes to demonstrate a science culture to students that is stereotypically "socially sterile, authoritarian, non-humanistic, positivistic, and (concerned with) absolute truth" (Aikenhead, 1996, p. 10). It is likely that such a science community would not find many citizens willing to live in it and would contradict many of the reasons why science literacy was emphasized in education reform in the first place.

Values as Indicators of Constructed Meaning: Student Preconceptions

Rather than being discouraged by its amorphous quality and ignoring the idea of science literacy altogether, discussing what science literacy might mean *explicitly with* students may engage students who miss implicit mechanisms by which science literacy may simply "happen" in science classes. Even if the class does not agree completely on a definition of science literacy, the discussion of what science literacy is will likely improve students' science literacy skills by demonstrating that science is not only about finding truth, but is also an expanding and continuous search. A note of caution is worth introducing at this point. The idea that science is a cultural enterprise rather than a canonical way of knowing has gained a great deal of support in the science education community, but not complete acceptance (Aikenhead, 1996). However, if one limits the definition of science literacy to "content mastery," a teacher could still benefit from a consideration of what types of science literacy can and should be attained in different classes.

As previously mentioned, many studies describe students' preconceptions of what it means to learn science: fewer consider teachers' values and the effects they may have on the learning process to foster and/or demonstrate science literacy. As Brown et al. (2005) make clear, "the teacher and students' co-construction of classroom discursive norms can have a significant influence of how students develop scientific literacy" (p. 790). Though the study focused on students' reactions to teacher comments, the implication is that teachers engage with students. Again, it is interesting the study focused on students and the affect their self-perceived identities had on co-construction of classroom discourse, but did not address the impact of discourse on teachers' identities or the impact of teachers' identities on discourse, even though teachers are obviously an integral part of the co-constructed discourse.

Values as Professed Pre-conceptions by Teachers

Assuming teachers are aware of science literacy as a key concept of Alberta Programs of Study, do they make their awareness explicit to their students? Brown et al. (2005) ask: "Would an examination of discursive identity and students' scientific literacy development differ significantly in AP® (Advanced Placement) science courses and their sheltered language counterparts?" (p. 789). The only way to answer such a question, of course, is to engage in research *within* different learning groups in different streams of science. Brown et al. later suggest that "being seen as a college-bound student by the teacher requires one to engage in the practices that are common to college-bound students (p. 789), but they do not explicitly suggest that teachers may change their practices in relation to students' views in a reciprocal manner. Thus, teachers' pre-conceptions of science students and science literacy in different streams must be examined. As Fensham (2004) points out:

> The shift in focus, from teachers and their teaching of the phenomena and concepts of science to learners and their engagements with these phenomena and concepts of science, is probably the most remarkable example of progression that has thus far occurred in science education research. (p. 16)

The question of what might happen if teachers do not consider their own pre-conceptions of science literacy in classrooms is described by Schriver and Czerniak (1999) who find that "young and adolescent youth…are vulnerable to failing in school and losing interest in science" (p. 21), despite the implementation of nation-wide calls for science literacy for all students. Schriver and Czerniak remind us there is a failure to recognize individual teachers' beliefs and that "teachers are the key to successful reform" (p. 22). In particular, Schriver and Czerniak suggest that increasing teacher self-efficacy positively correlates with teachers' levels of knowledge and students' motivation in science. Perhaps even more interesting is that Schriver and Czerniak found that junior high teachers had less knowledge of developmentally-appropriate curriculum and instruction than their peers in middle school. Would the same deficiencies be found in a study of Alberta high school teachers over various grades and streams?

Barnett and Hodson (2001) also make clear the necessity to consider teaching context. They develop a coding system that recognizes the "micro-worlds" (p. 434) that interact to affect a teacher's delivery of his/her planned curriculum. These include micro-worlds of science education (science literacy, citizenship, environmentalism); teacher professionalism (competence, credibility, influence, and self-promotion); science curricula (keeping current, assessment/evaluation procedures, accountability); and the particular school culture (its "ethos" or "ground rules"). These micro-worlds, once defined, could help clarify various teachers' perspectives on and pre-conceptions about science literacy. As Man-Wai Chu (2009) points out in a thesis concerning delivery of the Alberta Physics Program of Study: "Each perspective brings a different quality to the classroom, therefore providing students with potentially different views of the same course" (p. 2). However, Chu admits that "…the objective of this thesis is not to understand in great detail what each teacher focuses on" (Chu, 2009, p. 2). This provides an opportunity to complement her work by focusing on the science literacy values a particular teacher espouses.

If teachers of different grade levels and/or different streams of science courses *do* approach science literacy differently in each of their classes, are shifts in their teaching practice from class to class only content-knowledge based or more considerate of the context that *frames* that content? This question is more important for the many teachers in Alberta who teach multiple subjects, at different grades, and in different streams. Is it necessary and, if so, is it possible for these teachers to substantially shift their view of science literacy for each of the different populations of students they are interacting with?

Analytical Framework

To address these questions, I sought other studies that explored how teachers communicated their views of science literacy and found that Corrigan, Cooper, Keast, and King (2010) and Cooper and Corrigan (2011) had conducted similar investigations into manifestations of teachers' science literacy values in lower and senior secondary science courses in Australia.

Corrigan et al. (2010) and Cooper and Corrigan (2011) describe how values, which provide guides to behaviour and/or points of reference from which to make decisions, can be used by teachers to appreciate how diverse positions can be embedded in curricula by making the often implicit teaching of science literacy more explicit. More specifically, the researchers interviewed teachers as to what they felt were the most important aspects of science literacy, then compared these professed statements to manifestations of these "values" within the classroom, followed by discussion with the teacher participants. To carry out this comparison, they melded Corrigan and Gunstone's (2007) work on dimensions of science with Siddique's (2008) work on manifestation of science values to develop the conceptual framework shown below (Table 1, modified from Cooper & Corrigan, 2011).

Table 1

Conceptual Framework for the Manifestation of Values of Science in Teachers' Practice

	Themes of Science Listed as Four Domains			
	Cognitive Dimension	**Science as Process**	**Human Qualities**	**Societal Dimension**
Values of and in science education (*Placed under the four domains*)	-Rational thinking -Skepticism -Search for Evidence	-Accuracy -Parsimony -Reliability -Validity -Empiricism -Collaboration/ Science Community	-Curiosity -Creativity -Open-mindedness -Ethics -Honesty -Integrity	-Reduction of bias -Interdependence (Connections and applicability) -Lens for meaning making
Pedagogical Practices	**Examples** -producing an argument -questioning -challenging -'playing devil's advocate'	**Examples** -repeating experiments -considering errors -calibrating equipment -looking for simplest explanation -reaching consensus	**Examples** -asking questions -brainstorming -acceptance of ideas/other interpretations -reporting/ communicating what actually happened	**Examples** -role play -considering what's the same or different -using analogies -how is this explanation different from what I understand?

Note. Adapted from Cooper and Corrigan, 2011

This framework places values of science under four domains: Cognitive, Science as Process, Human Qualities, and Societal. The Cognitive domain includes those values that help learners to understand what it means to think critically about an issue by challenging current theories and practices, with the understanding that science may not always provide the best answers (Monash University, 2014a). Values in this domain include rationality and use of logic when approaching a problem. Not only is skepticism of others' claims valued, but so is the demand for evidence to verify those claims (Corrigan et al., 2010). The Science as Process domain promotes values of empiricism (direct experience and experimentation), parsimony (choosing the simplest explanation), reliability (can it be repeated), validity (is it testing what is says it is), accuracy (precision in measurement and authenticity in observation), and consensus that scientists use to collect, observe, and analyze data in order to build understanding about the world (Monash University, 2014b; Corrigan et al., 2010). The Human Qualities domain recognizes the values of the real people who are thinking about and creating scientific knowledge, and the roles that creativity (imagination, innovation, and inference); curiousity (inquisitiveness/desire to know more); open mindedness (acceptance of multiple interpretations); and ethics (honesty and integrity in behaviour) play in generating new knowledge (Monash University, 2014c; Corrigan et al., 2010). The Societal domain recognizes the contributions of scientists to society and promotes values such as meaning making and recognition of the interdependence amongst science, technology, society, and nature. In this way, science can be seen as a useful tool developed for exploring and facing societal challenges in an objective and sustainable way, with any biases as clearly defined as possible (Monash University, 2014d; Corrigan et al., 2010).

Cooper and Corrigan (2011) used the four main domains, and the values associated with them, to code transcripts of interviews with and observations of the teacher participants' classes to compare professed values with manifested values. Corrigan et al. (2010) included "Longing to Know and Understand" in the Human

Qualities domain, "Diversity of Science Thinking" and "Valuing Process" in the Science as Process domain, and "Interdependence" in the Societal domain. In both papers, the researchers discussed these codings with the teacher participants to clarify any misinterpretations and to stimulate discussion on how teachers' values can influence their delivery of curriculum in both implicit and explicit ways. This process clearly demonstrated how self-reflection carried out by teachers can lead to deeper understandings about how and why they teach science the way they do. The framework has already been used for teacher self-reflection in other studies (see Keast and Cooper, 2012), demonstrating its versatility in providing a practical tool for stimulating deep conversations amongst both new and experienced teachers.

Teachers as Learners

Returning focus to teachers in my study is not meant to suggest students are unimportant. On the contrary, recent studies on students most certainly helped inform my study. The revelations from student group identity studies demonstrate how important it is for teachers to reconsider, or at least make explicit, their own approaches to classrooms. With what we have learned about changes occurring in students' identities as they learn science, we can consider whether similar changes in teachers' perceptions of science literacy occur due to impacts from their students. Paulo Freire (2002) states that "students never discover that they educate the teacher" (p. 72): my study therefore also begins to question whether teachers themselves know they are being educated by their students. If we want teachers to model self-reflection in science literacy, as discourse studies seem to imply, then Freire's call for a teacher to be "no longer merely the-one-who-teaches, but one who is himself taught in dialogue with the students, who in turn while being taught also teaches" (p. 80) becomes increasingly relevant. The application of Freire's call is intended to open teachers' minds to the thoughts of their students in hopes of improving dialogues about the diversity of science literacy needs. Through the mutual learning process, teachers may comprehend science literacy as being necessarily different for different grades and streams of students. If this comprehension is made explicit, the benefit for future students in that grade and/or stream becomes more apparent. Teachers who understand what each particular learning cooperative can accomplish together make learning goals – such as science literacy – clearer to their students. Teachers can make reflective practice and sharing of ideas explicit and invite students to do the same. As such, the framework provided by Corrigan et al. (2010) and Cooper and Corrigan (2011) could also be used to perform an analysis of *student impressions* of the teacher's science literacy values, enabling a reciprocal learning process. In this way, the framework could report manifestation of values by the teacher *and* how these values are understood by the students.

Summary and Reconsideration of Research Question

Boote and Beile (2005) stress that a literature review should not simply lead to research that mirrors that which was done before, but rather should lead to "new, productive work" (p. 6). In what sense is the current study productive in its synthesis of previous research?

In the literature review, one can see that: "Little, if any, consideration is given to the nature of the subject matter by the science teachers in the decision making. Implications exist for the disenfranchisement of teachers from the task of making decisions concerning what to teach" (Duschl & Wright, 1989, p. 467). Shamos (1995) makes such disillusionment amongst teachers explicit with the failure of many past efforts to mandate science literacy on a national level. This study hopes to explore what consideration is given by teachers to science literacy in Alberta classrooms. Though the diversity of contexts faced by science teachers has been extensively studied, manifestations of a teacher's science literacy values may not be as diverse as the classroom settings in which they occur. By focusing on manifestation of science literacy values as Corrigan et al. (2010) and Cooper and Corrigan (2011) did, it is hoped my study will clarify whether a balanced consideration of science literacy occurs not only in the minds, but also in the practice of teachers as mandated in all Alberta Secondary Science Programs of Study in a way that allows students to appreciate, if not internalize, the complexity of science literacy. To do this, my study will extend the work of Corrigan et al. (2010) and Cooper and Corrigan (2011) to consider the values expressed by the student participants also (not just those of a teacher), to see if and how a teacher's professed values are understood by his students in two different levels of science classes (Science 10 and Physics 30AP).

If practicing teachers are to gain from this study, the results must be communicated in a format they can readily access and appreciate. This may not be the case for several of the studies which have been mentioned here as many teachers may never find the time or develop the inclination to seek them out in research journals. In summary, it is hoped that this study will be: (a) reflective of the varied contexts in which teachers find themselves in dialogue with students, (b) capable of providing examples of teacher reflection on practice and student perceptions that can be used by teachers themselves, and (c) presented in a format that is accessible to teachers. Indeed, as described by Corrigan et al. (2010), the use of values allows for a:

> …powerful way of considering aspects of the common tensions between researchers and teachers; researchers often focus on the 'intellectual' work of teachers, while teachers tend to be more concerned with the 'emotional' and 'organizational' forms of teachers' work. (p. 1)

In Chapters 3 and 4, a discussion of how Corrigan et al. (2010) and Cooper and Corrigan's (2011) framework was modified and applied to my own data will allow for consideration of whether teachers and students will indeed find this research accessible and practical.

CHAPTER 3: RESEARCH DESIGN AND METHODS

Introduction

This chapter will begin by describing and providing the rationale behind the choice of a qualitative study and the study setting itself. It will then more fully define the methods used to collect data from the participants – namely the teacher and students – and how each of these methods contributed to a deeper understanding of the manifestation and acceptance of science literacy values in the classroom. After discussing how these data were analyzed, the chapter ends with a discussion of the trustworthiness of the selected methods, acknowledging limitations that may be inherent in the same.

Research Methodology

This study utilized qualitative research methods (Creswell, 2009) incorporating an interpretive inquiry strategy to explore the complexities of science literacy in the classroom. The rationale for adopting this approach are provided in the following two sub-sections.

Why Qualitative?

The current study took a fully qualitative approach, engaging in low-level inference research (Ercikan & Roth, 2006) contingent on particular classroom contexts and close involvement with the participants for whom the results are intended. Maxwell (2004) notes quantitative research is better suited for research that involves: (a) testing a well-developed theory through controlled experimentation, (b) causal processes that are free from temporal and contextual variability, and (c) phenomena that are not directly observable. As has been discussed, science literacy is not clearly defined and was not being tested as an application in this study. As the meaning of science literacy has changed dramatically over time and in different locations, direct observation of classroom behaviour, from a non-participant perspective, allowed for consideration of the values expressed in each unique setting of each class grouping being studied. Neither the teacher nor the students were asked to alter their regular behaviours or classroom activities, nor were they given differential treatment as part of the study. This was intentionally done to allow an authentic view of the teaching practice, not change it to suit the needs of the research.

One goal of this study was to explore how science literacy values were understood by the teacher and students, not to prescribe which values (if any) should be given priority in teaching. Science literacy, in this study, was not seen as a concept to be transmitted, but to be interpreted (Sutton, 1996) by the students and teacher. As Hostetler (2005) points out, too much research "tends to end with an answer" (p. 21). It was intended that this study remain as open as possible to the real situations that occur in a classroom, preventing premature foreclosure. In this sense, my study agrees with Barnett and Hodson (2001) in that its purpose had: "…less to do with deciding what it is that science teachers *should* know/do and more to do with unpacking the extraordinarily complex knowledge on which skilled science teachers draw in their daily practice" (p. 449). Guba and Lincoln (1994, p. 106) suggest qualitative methods provide openness to complexity by not stripping science literacy of its contexts; by allowing insight into human behaviours; by preventing discrepancy between "insider" (teacher as practitioner) and "outsider" (researcher as theorist); and by allowing for discoveries to emerge from the study rather than engage in verification of previous studies. Hitchcock and Hughes

(1995) echo these sentiments, stating that qualitative research is inductive, not concerned with "testing" of pre-formulated hypotheses, but practiced as "emergent, creative and open-ended" (p. 116). Though Firestone (1987) argues against blind acceptance of purist views of quantitative and qualitative studies, he acknowledges that quantitative studies typically represent more positivistic aspects of a situation while qualitative studies assume "multiple realities that are socially defined" (p. 16). As my study addresses science literacy by considering the values expressed by a teacher and his students, a qualitative approach is an appropriate one to take.

Why Interpretive Inquiry?

As Ercikan and Roth (2006) point out: "…different people…need different forms of knowledge to make decisions" (p. 23). It is my contention that rich descriptions such as those provided by a qualitative inquiry approach best emulate the context in which teachers find themselves exploring, modeling, and teaching science literacy. Agreeing with Berliner (2002) that the "power of contexts" (p. 19) cannot be ignored in educational research, I intended to treat each class grouping as separate, within which students and their teacher could interpret values of science literacy. As a practicing teacher myself, I knew it would be a challenge to not focus on certain aspects of the teaching process. However, as I was not involved with delivery or assessment of course content and was collecting data through various methods (especially through continuously running audio and video recording), I hoped to gather enough data to enable me to "discover" phenomena that I myself did not focus on initially while recording field notes. By focusing on the values of science literacy rather than on the content of the science taught, the audio and video recordings helped me "make things strange...[and to]…view each aspect of the phenomena as if it were new and unfamiliar and, hence, potentially significant" (LeCompte, & Preissle, 1984, p. 240). This was the beginning of the inquiry of my own interpretations, which then allowed me to share my own thoughts with the students and teacher to determine if their interpretations were similar.

A personal narrative or self-study could have addressed some of my questions, but may also have prevented alternative viewpoints from arising from the teacher participant who may have either: (a) not read the same literature as I have on the subject, or (b) not had the motive or opportunity to consider science literacy as a framing concept for his teaching. By allowing the teacher's views to emerge from his own practice, I believe there is a greater potential for the experience to be deemed valuable to him and to other teachers. As exploratory discourse about science literacy amongst teaching professionals is one aspect of the study, allowing a natural emergence of manifestations of science literacy values from classroom cultures seemed well-suited to an interpretive inquiry approach. By excluding my own students in my interviews and observations, I ran less risk of influencing students' perceptions of the teaching process that may have occurred had they been eager to provide what they may have perceived to be the "correct" answers to my questions to earn favour or some other credit.

Study Setting

The study site is a mid-sized (1500 students) urban high school that uses a semestered format, which provided the opportunity to see several classes and permitted full observation of several complete lessons in each class. As teachers in this school regularly teach different course levels and streams and colleague inter-visitations amongst classrooms are a part of this school's culture, the data collected represented real classroom situations with minimal distortion due to the presence of a researcher. All observations and interviews took place between September 14, 2011 and June 22, 2012.

Course Differences

In order to obtain a high school Diploma in Alberta, students are required to complete at least two courses (10 credits) in science (Alberta Education, 2014, pp. 85-86). As such, it is possible the last time students are exposed to a systematic explanation of science concepts and science literacy could be in the tenth Grade. Many students take more than the minimum number of science courses and are exposed to different discipline-specific science content and concepts in Biology, Chemistry, and Physics. Yet, as previously mentioned, all high school science Programs of Study, regardless of discipline, have a common statement with respect to science literacy. Thus, a high school presented an ideal location for the study of science literacy as it *could* be "valued" in different ways in different contexts within one building. As the school in this study also offers AP® science courses, the potential to consider international curricula of a higher stream was also realized. To incorporate science literacy values of both "new" and "experienced" high school science students, a Science 10 and a Physics 30AP class were selected for study in one teacher's portfolio to see how, if at all, that teacher taught his values of science literacy differently. This could indeed be the case as Science 10 and Physics 30AP, though both science courses, serve different purposes. Science 10 is a first year, entry-level high school course that covers general topics over a wide range of disciplines (biology, chemistry, ecology, global systems, physics); Physics 30AP is a course that is meant to prepare students for science courses, particularly in physics or engineering disciplines, in post-secondary institutions.

Participants

Teacher: Selection and Omission Criteria.

The selection of a teacher for this study was based on diversity of classes taught and included an experienced (more than 20 years) teacher to ensure comfort with subject-knowledge in all the courses he taught. Teachers who were only teaching multiple sections of the same course were not considered for inclusion. Only one teacher was selected for the study due to observation and time restraints, which are more fully described later in the chapter (see "*Limitations*", p.60).

Students: Selection and Omission Criteria.

After two separate subjects, streams, and grade levels of classes with the same teacher were chosen by the researcher from the teacher participant's timetable, selection of student participants was completed. From those students who had full parental consent to participate in the study, preference was given to students who reflected a desire and commitment to engage in all aspects of the study from beginning to end (which included a commitment to being present for each class during which observations would occur and taking part in interviews). For each class, one male and one female student were selected from this subset to provide some degree of control over potential sex/gender bias that could emerge.

Participant Profiles.

In total, one teacher and four students were engaged in this study. The teacher, Neil (pseudonym) selected for this study was a highly experienced teacher. Neil was nearing the end of his teaching career. He has received numerous awards and commendations for teaching excellence at provincial, national, and international levels.

As he was teaching both a regular General Science 10 course and an advanced Physics 30AP® course during openings in my own teaching schedule, Neil seemed an ideal candidate for my study. From each of two courses taught by Neil (Science 10 and Physics 30AP®) I selected two students (four total). These students were interviewed twice each. The Science 10 students (Jack and Jill) were just beginning Grade 10 and this was their "first" high school level science course, while the Physics 30AP® students (Marie and Albert) both were in Grade 12 and had completed (or were just in the process of completing) all three disciplines of science (Biology, Chemistry, and Physics) with both choosing to take two of the three sciences up to the 30AP® stream (for Marie, Chemistry and Physics; for Albert, Biology and Physics). As such, the courses *and* the students in these courses provided very disparate learning contexts and experience levels within the broader high school science population.

Ethical Considerations

Before choosing participants, this study was reviewed and approved for its adherence to ethical guidelines by the Education, Extension, Augustana, Campus Saint Jean Research Ethics Board (EEASJREB) at the University of Alberta. This study also adhered to the University of Alberta Standards for the Protection of Human Research Participants through the Human Ethics Research Online (HERO) application process and the research ethics requirements for Edmonton Public Schools Research Proposal Criteria (Cooperative Activities Program) (See Appendix A). Research ethics training was also part of my Graduate program courses at the University of Alberta.

Research Methods/Data Collection

Any study of delivery of curriculum should consider the inner perspective of the individual teacher and the outer perspective of the class as a whole. To avoid "hammering reality into shape" (Hitchcock & Hughes, 1995, p. 97), I used several strategies so multiple perspectives could maintain privilege throughout the process (Peshkin, 2000).

After the teacher participant was informed of all the aspects of this study, and he consented to participate, two different classes in the teacher's portfolio were selected. The study details were then presented to each class and after questions arising from this presentation were answered, letters and consent and assent forms were distributed to all students and their parents/guardians. Only once signed forms were returned did data collection begin.

The following methods were used to uncover how teachers defined and demonstrated science literacy values in their classrooms: (a) open-ended interviews with students and teachers; (b) in-class observations utilizing researcher field notes, and audio and video recordings; and (c) member-checking to review data and initial findings with participants.

Why Interviews?

Non-standardized interviews were used to get at participants' "mental phenomena" (Maxwell, 2004). Hitchcock and Hughes (1995, p. 153) list five approaches to non-standardized interviews. Of these, the ethnographic, or unstructured interview, was selected for this study as it provides a "situated account" (p. 160) of teaching, although it must be made clear that a full ethnographic approach was not used due to time and materiel access constraints. “Unstructured” means the interviewer was free to change the order of questions or spend more time on some questions than others as ideas emerged from interview conversations (Hitchcock & Hughes, 1995). Overly structured interviews could have precluded participants’ unique experiences of the study, limiting the abilities of the participants to act as co-inquirers in the process.

From the outset of the study, I made my relationship to the participants clear, ensuring confidentiality of data collected and preservation of anonymity in data reports, while reiterating that no evaluation was taking place. To prevent perceptions of evaluation of their teacher by students in their interviews, I utilized Piburn and Baker’s (1993) suggestion and asked students questions like: “If *YOU* were the teacher, what would you do in your science class?” (p. 395). “Science literacy” was only mentioned near the end of interviews to: (a) allow participants to tell me what they thought was important about science without getting stuck on “literacy” as a definition, and (b) explore whether the term had been used before in this or other classes. The intention was not to derive a single definition or suggestion of how science literacy should be taught, but to enable participants to express their own interpretations and allow them to consider both the internal disciplinarity and external relativity of science literacy (Roberts, 2007) while engaging with the Alberta Science Programs of Study.

Questions such as: “Is there anything we did not talk about that you would like to add to this discussion?” allowed participants to take discussions in new directions or to reinforce ideas or themes they deemed particularly important, while ensuring accurate interpretation of their own thoughts and values. Audio recordings were used to ensure accurate transcription, freeing the researcher to make notes about key points or participant actions during the interviews.

Timing of Interviews

Each of the four students was interviewed twice: once before and once after the class observations were carried out. The "pre-observation" interviews (between 7 and 11 minutes long) addressed student science literacy experiences and/or what skills they expected a graduate of their course to gain. The "post-observation" student interviews (between 8 and 40 minutes long) sought to determine if any changes in perception or emphases in students had occurred and whether such changes corresponded to teacher predicted and/or perceived changes for those classes.

Teacher interviews took place before observations ("initial"), after two weeks and observations ("mid-observation"), and after final class observations ("post-observation"). More time was allotted for these interviews because it was expected the teacher would have more to say about his practice of teaching and he would be responding to material collected from observations that required time for thinking, reflection, and report. As such, these interviews took place outside of school hours and took 20 minutes (initial interview), 40 minutes (mid-observation interview), and 90 minutes (post-observation interview).

Teacher interview questions were more "technical" in nature to clarify the teacher's classroom practice. However, as with student interviews, any comments that generated deeper responses or discussion were given attention. The "initial" teacher interview allowed: (a) the teacher to become more comfortable with the researcher, and (b) the teacher to define what his notions and values of science literacy were before classroom examples of values were discussed. The Program of Studies science literacy statement was not included so the teacher's perspectives and experiences either emerged or remained hidden during the interviews.

Teacher interviews at "mid-observation" and "post-observation" periods allowed: (a) teacher input on data collected and interpreted by the researcher, (b) opportunities to reflect on various events/moments in the classes, and (c) opportunities to see if the teacher's views on how he was conducting his classes was affected by the study. The "post-observation" teacher interview included questions about shifts the teacher noticed in his students' understanding of science literacy to allow comparison to students' reports.

Midpoint and final teacher interview scripts were developed *after* observations so: (a) contextual classroom references could be included, and (b) comments from initial interviews could be expanded upon later. Mid-point and final interviews for both teacher and student participants included participants' questions and comments to ensure they maintained active and generative roles in the interpretive process.

Why (and how) Observations Were Done

Just as interviews captured and recorded mental phenomena, videotaped observations of teaching allowed for "natural phenomena" (Maxwell, 2004) involving the teacher and his students to be recorded. Each class (Science 10 and Physics 30AP) was observed four times, for 81 minutes each time (for a total of 324 minutes in each class), between September 14, 2011 and December 12, 2011. According to Aikenhead (2006), about 90% of science teachers endorse implementation of humanistic perspectives, but provide many reasons for not doing so. As this study considered science literacy to include both content and sociocultural application of science knowledge, what teachers *do* and *how they do it* was as important as what they *say* they will do to promote science literacy in different contexts. Saying one will do something does not mean it will be done. Thus, full video and audio recordings of these classes provided: (a) context for comments made by participants about classes during interviews, (b) video clips to stimulate recall about classroom activities, and (c) confirming and/or disconfirming evidence in relation to what a teacher perceived was happening and what was really happening with respect to science literacy values in his classrooms.

Field Notes

Field notes during observations were kept separate from transcriptions, allowing "clean" copies of transcripts for alternative interpretations later in the study (Hitchcock & Hughes, 1995). These notes also allowed for time marking of significant events (Tobin & McRobbie, 1997) to more easily cross-reference, and provide context to, recordings. This allowed for selection of relevant sections of recordings to discuss with the teacher in subsequent interviews and more accurate contextualization of audio and video recordings during transcript coding.

Audio and Video Recordings

Audio and video recordings allowed for "unfiltered" data collection: equipment was not paused or "focused," permitting greater openness of interpretation of class activities. Both formats allowed for recording of vocal qualities that suggested changes in the teacher's approach to material that may have been missed by the researcher while recording field notes.

Video recordings offered the added benefit of capturing teacher movement and non-verbal communication. Though this may have added pressure on the teacher while being videotaped, the camera itself was set up to not obstruct teacher movement (using a wide angle from the back of the room) and was not focused or re-situated to suggest bias towards or against any teaching techniques. Barnett and Hodson (2001) remind us teachers are often required to "'think on their feet' and to constantly adjust their approach in order to ensure satisfactory learning progress for their students" (p. 428). Video recordings can catch moments in which such adjustments are not audible, but visual (for example, proximity to certain students, hand/body gestures, pointing out a classroom resource).

Why Member Check?

Member checking was used to confirm the students' and teacher's science literacy values and manifestations in class were being accurately interpreted by the researcher. As Tobin (1992) describes, sharing only final interpretations can generate opposing frameworks which cannot be reconciled between the teacher and researcher. Member checking allowed participants to "check intentionality and errors that might have been made either by the participants or the researchers" and allowed them to "agree or disagree with the assertions of the research, and suggest corrections, elaborations, and summary statements" (Tobin & McRobbie, 1997, p. 359). Some examples of member checking have already been mentioned (participant summaries of interview notes and discussion of choices made during class activities) that made clear to participants that their active involvement in interpretation was essential to the study. As all interpretive acts are generative (Peshkin, 2000), opportunity was provided for new discussions to emerge.

Erickson (1986) reminds us that "research on teaching, through its inherent reflectiveness, helps researchers and teachers *make the familiar strange* and interesting again" (p. 121). Teachers with whom I discussed this study agreed that opportunities to "talk" to colleagues in reflective ways are lacking in frequency and quality.

Erickson's (1986) concern of "evidentiary inadequacies" (p. 140) were addressed by ensuring that: (a) adequate evidence had been collected, (b) there was variety in the evidence collected, (c) observations were carried out for long enough to uncover main themes and/or verify claims, (d) disconfirming evidence was strongly considered, and (e) discrepant cases were developed to test them against confirming cases.

On a more practical note, perpetual sharing of data also ensured that interpretation of observations was occurring while the data were still "fresh" in the mind of the researcher. In being required to provide feedback to participants, the study maintained momentum without data going "stale" and avoided omission of key observations that could not be verified at a later date.

Data Analysis

In Chapters 1, 2, and 3, the difficulty in defining science literacy demonstrated the importance of finding an analysis method that would allow for the observation of the many facets of science literacy that could appear in a science classroom. The ability to discuss and observe teacher and students' "attitudes" and "opinions" *about* science literacy is important to the teaching relationship if there is to be any attempt to engage students to develop a lifelong appreciation of science through its value to their lives. With this notion of "*what is of value*" in mind, the analytical framework of Corrigan et al. (2010) and Cooper and Corrigan (2011) was modified and incorporated into my research.

As mentioned in the literature review (see page 31), these researchers had successfully investigated manifestations of science literacy by using a values approach that allowed for a great deal of collegial reflection. In my own study, the analytical framework was used to identify frequencies of reported science literacy values in the transcripts of all teacher and student interviews and frequencies of manifested science literacy values in transcripts of the classroom observations. These frequencies could then be compared to determine how effectively the teacher's professed science literacy values were being communicated and identified by his students.

Identification of Themes/Value Categories

Erickson (1986) suggests that when researchers do not include a "discussion of the ways in which key concepts in the analysis evolved or unexpected patterns were encountered…this is an unfortunate omission" (p. 152) because the final interpretation gains plausibility when the researcher can demonstrate the careful thought and considerations that went into developing it. The more detail included in the researcher's "natural history," the greater potential for readers to develop understanding of what occurred. Hitchcock and Hughes (1995) discuss a similar practice of producing "the reflexive account," or "reflective commentary," which is also meant to be "an honest, open and critical account of the course of the research and its major strengths and weaknesses" (p. 103). While consideration of strengths and weaknesses of my methods is covered later in this chapter, one example of how reflection on the research process was used to improve the method used is worth mentioning here.

Following the work of Corrigan et al. (2010) and Cooper and Corrigan (2011), the values used for analysis in my own study were categorized under four domains (science as process, human qualities, cognitive dimensions, and societal dimensions). Each domain was further divided into more specific value categories that reflect manifestations of these domains. Each of the specific "Value" categories in the modified analytical framework were then set as nodes to allow for coding of all of the transcripts using nVivo™ 10 Software.

However, as initial interview and class observation transcripts were being coded, it became apparent that the re-inclusion of some of the values of Siddique (2008) that Corrigan et al. (2010) and Cooper and Corrigan (2011) did not include in their framework (namely, "Different forms of science inquiry", "The tentative nature of science", and "Historical aspect of science") were important to more fully capture the experiences of the participants. I also added my own manifestation values: "Developing Models" (under the Science as Process dimension), "Building Student Confidence in Science" (under the Human Qualities dimension), delivering "Facts of Science" (as a new category to deal with comments valuing factual recall in science), and "Other" to deal with comments mentioning science in more ambiguous terms, but still suggesting an inherent (though more implied) value to the participants. Examples from the transcripts of the teacher interviews that support the addition of these values are provided in Table 2, and full tables of the value categories making up the modified analytical framework chart can be viewed in Appendices B, C, and D.

Table 2 ***Values Added to the Analytical Framework of Corrigan, Cooper, Keast and King (2010) and Cooper and Corrigan (2011).***	
Name of Domain: *Specific Value in Domain*	***Examples of Manifestation from Teacher Interviews***
Science as Process: *Different forms of science inquiry (Siddique)*	"…the more the discussion leads to another possible way you can get kids to actually do something, I think that works better." (I-3)
Science as Process: *The tentative nature of science (Siddique)*	"And everything in science is supposed to be a working model for now." (I-2)
Societal Values: *Historical aspect of science (Siddique)*	"…you know you're still teaching the physics, but you're talking about who did what, and this kind of thing, that, uh, that helps them learn." (I-2)
Science as Process: *Developing Models (Henkelman)*	"In junior high, you needed to know it, you needed a simpler model, for what you needed to do", uh, "We need a little bit different model for what we wanna do now" and it's all about models" (I-1)
Human Qualities: *Building Student Confidence in Science (Henkelman)*	"So, doing labs is a threat. Not because they might not finish it, but because they're confident that they can get the answers, paper and pencil." (I-1)
Facts of Science: Importance of factual recall *(Henkelman)*	"…we still have to go through the, the grunt work, I guess it is, of getting them to know the stuff they have to know." (I-2)
Other: Ambiguous importance of science education *(Henkelman)*	"…because I told her (a female student) she didn't have to believe it (evolution as a concept), then she's happy to answer my questions (about evolution on a test) for me, which is kind of interesting." (I-1)

By adding these categories to Corrigan et al. (2010) and Cooper and Corrigan's (2011) original framework, I was able to honour the importance of these ideas to the teacher and students and to determine the relative "value" the teacher and students attributed to these categories in word and deed. As coding progressed, it became possible to compare the frequencies of each value and draw conclusions that would address the research question (see Chapters 4 and 5). It is worth noting, however, that after analysis some limitations of this framework did become apparent. These limitations are discussed later in this chapter (***Limitations***) and under ***Potential for Ongoing Research*** in Chapter 5.

Trustworthiness

According to Hitchcock and Hughes (1995), it is important that "…material collected by the researcher presents a true and accurate picture of what it is claimed is being described" (p. 105). Shenton (2004) further details criteria of trustworthiness in qualitative research first developed by Guba (1981). More specifically, Shenton (2004) cautions researchers to consider credibility, transferability, dependability, and confirmability to ensure that their work is trustworthy.

Credibility

In order to ensure this research was congruent with what the participants in the study were experiencing, several aspects of credibility defined by Shenton (2004) have been considered in the collection and analysis of the data. Triangulation of the data (Mathison, 1988; Shenton, 2004) through interviews, researcher field notes, and audio and video recordings of class activities was carefully considered and enabled synthesis of context rich coding choices. Honesty on the part of the participants was promoted by ensuring they fully understood the project and were made aware that they could leave the study at any time or have their comments stricken from the data. Follow up interviews allowed for iterative questioning, to uncover any contradictory statements. Member checks were performed throughout and reflective commentary has been provided with sample coding of the data (see Appendices C and D) to help clarify the choices made. These Appendices provide examples of the values that appeared in the transcripts, using specific quotations from the transcripts collected (teacher and student interviews and Science 10 and Physics 30AP class observations).

To help provide a “thick description of the phenomenon under scrutiny” (Shenton, 2004), an extended example of coding is also provided below, taken from the first teacher interview when Neil was asked what “science literacy” meant to him:

> ***Neil:*** *I think the biggest thing it means is a…it’s a world view where you think about what’s going on, and why, and you experiment to find out if you’re right. So, basically- the scientific method. Um, that’s, that’s, I think, the number one thing. So if you watch a show like “The MythBusters”, they’re not that scientific, not really, but the world view they’re presenting is: let’s test it and see if it’s gonna work, kind of thing, you know, so, um, and, and for most of the kids, if that’s all they ever get and they develop a little bit of skepticism about, well, “You say this, but I’m gonna try it and see”, then I think, you know, that’s, that’s great for most of us. So, now, as secondary to that, the scientific method, you can formalize that with big words or small words, or whatever you want to do, and, and we have curricula that tells us we have to do that kind of thing, right. And then, and then there’s also a body of knowledge that we’ve learned as a result of the scientific method, and that’s part and parcel of the, of, of scientific literacy as well, so it’s sort of those three things I think.*

In this excerpt, several values are represented. In the Human Qualities domain, there are examples of the values of *Curiousity* (“Let’s test it and see if it’s gonna work”) and *Longing to Know and Understand* (“…a world view where you think about what’s going on, and why…”). In the Cognitive Dimensions domain, the values of *Search for Evidence* (“You say this, but I’m gonna try it and see”) and *Skepticism* (“…and they develop a little bit of skepticism…”) are present. In the Science as Process domain, the values of *Empiricism* (“…I’m gonna try it and see…”), *Science Community* (“…a body of knowledge that we’ve learned…”), and *Valuing Process* (“…you experiment to find out if you’re right. So basically – the scientific method”) can be seen. But we also see the value the teacher gives to students knowing and respecting the *Facts of Science* (“…there’s also a body of knowledge that we’ve learned…”) as being part of developing science literacy.

In the preceding example, we see instances while coding where a statement could have been or was coded in multiple ways. This brings to mind the same caution described by Cooper and Corrigan (2011):

> While some of the values in this framework may be open to debate and contestation (such as, is objectivity really a value or should it be something more akin to reducing bias as scientists are human and bring their own biases to their work), this framework, in linking the values with possible manifestations in the science classroom, does provide some useful insights into the often implicit teaching of science values. In this study, the manifestations were used to identify teaching practices that indicated a teacher's values; either through the teacher's actions or their (sic) words. (p. 2)

Context is very important in making choices about how to code statements or actions. When coding transcripts of class observations, video tape was used to observe non-verbal cues that suggested one meaning over another. In interviews, member-checking was used to ensure that coding was accurate. There were other times, however, when a single statement had to be coded under multiple values or divided into multiple categories and/or specific values. Consider the following examples where one sentence could be split to represent two values:

> ***Neil:*** *...you think about what's going on, and why, and you experiment to find out if you're right. (I-1)*
>
> ***Neil:*** *...human beings got where we were by noticing things, and trying them out again and again, and I think kids are like that. (I-3)*
>
> ***Neil:*** *Science says: "I think this is what's going on, I'll run an experiment to see". (I-3)*

In each of these cases, Neil was talking about how students are engaged in wondering why Nature works the way it does (a Human Quality of *Longing to Know and*

Understand), but he also suggested the means by which these questions can be answered: experimentation (a Process value of using the scientific method: *Valuing Process*). Thus, a single statement can represent a number of values at once, which made coding a more time-consuming process.

Transferability

Although qualitative research is specific to the context in which it occurs, Shenton's (2004) suggestion to include study setting, participant details, data collection method description, number and length of data collection session details, and the time period in which the data were collected have all been included in this paper to allow some degree of transferability on the part of the reader to other contexts. Discussions with other teacher colleagues and graduate advisors ensured the procedures outlined for this study would be feasible and lead to practical results. The fact that the analytical framework used in this study has already been used in other contexts inherently lends support to its transferability, though it would be expected that different teachers would have different values. As the purpose of this study was not to define teachers' values for them, nor even to define science literacy itself, transferability of specific findings was not taken as a primary goal. While the methods used to collect, code, and analyze the data collected in this study are reproducible, the question remains as to whether the results of this particular study could be generalized to other teachers, other students, other schools, other school districts, and even other countries. As the goal of this research was to explore how one teacher's science literacy values were manifested in his classes, and how those values were perceived by his students, it could be argued that the results of this research do not extend beyond those classroom walls. It may very well be true that the specific *frequencies* of the various science value domains and categories observed for Neil would never be specifically reproduced in other classes, or even in any of Neil's future classes. To consider the transferability of this study, however, it is crucial to remember the ***essence*** of what the study meant to reveal: To what extent are a teacher's *professed values* of science literacy communicated to and understood by students in different classroom contexts? As each teacher may have different values of science literacy to start with, the coding of values in the interviews could be expected to vary widely from teacher to teacher. The coding of a teacher's professed values might mean nothing without considering how the teacher *manifests* those values during classroom sessions. It is possible that other teachers could profess an emphasis of the same values as those expressed by Neil, but with vastly different frequency of manifestation. It is also possible that other teachers could clearly profess and emphasize different science literacy values altogether. Thus, transferability in terms of comparison of how often certain values occur for different teachers is neither the strength nor purpose of this type of research. Rather, this study was and is meant to facilitate discussions with and amongst teachers to help them recognize their *own* strengths, biases in values, and student perceptions of their teaching. If research is conducted in this spirit, with teachers and students who are willing to welcome a researcher into their classrooms, studies like this could benefit various science disciplines, grade levels, academic streams, enrichment programs, remedial programs, and science teachers of any level of experience.

Dependability

Like transferability, dependability requires the researcher to clearly describe the methods another researcher may use to gain similar results (Shenton, 2004). Shenton

(2004) also stresses the importance of “overlapping methods” (p. 71), to provide internal dependability. It is hoped that the details provided in this paper regarding the research design and its implementation, details on how data were collected, and reflection on the process carried out would enable similar investigations in the future. The use of two students from each class to report on their perceptions of science literacy values, and multiple class observations by the researcher of both groups also provided some degree of dependability within each class.

Confirmability

Shenton (2004) states that the work’s findings have to come from the experiences and ideas of the participants, not from the researcher. Though I have reported my own view of how science literacy can be defined in Chapter 1, I chose not to share that definition with the participants, allowing them to report their own interpretations to me throughout. By using three different sources to develop my transcripts (field notes, video, and audio recordings), and by using through-study member checking and peer-debriefing to ensure accuracy of those transcripts, researcher bias was minimized. A thorough review of the codings during quantification and while finding examples for the sample coding table also allowed for checking of a consistent application of definitions of the values across student and teacher interviews and classroom transcripts. To help ensure there is a clear “audit-trail” leading to the answer to the research question, the results of the analysis presented in Chapter 4 will be presented sequentially in building toward an answer to the research question.

Limitations

Understanding that qualitative research relies on contextual awareness, the limitations of the current study will be outlined by considering the study setting and data collection and analysis methods.

As I am currently a science teacher at the school in which the observations took place, it is possible that my own academic background (though not in the disciplines studied here) and "insider knowledge" of the school and the teacher may have biased my interpretive choices in ways of which I was unaware. Though this might improve local credibility of the findings, and may not affect transferability (other researchers may have similar intimate knowledge of their own study settings), it would need to be considered to help ensure dependability of the results.

As stated previously, Science 10 and Physics 30AP classes are inherently different courses with different student populations. From this, we must remember that Science 10 students may struggle very early on in the course and never take another science course in high school (or beyond high school), whereas Physics 30AP students have already demonstrated success at the Science 10 and Physics 20 levels to qualify for Physics 30AP. As a result, some of the science literacy values mentioned by the Physics 30AP students may come from school science teachers other than Neil, who was involved in this study. Though to a lesser degree, this possibility also applies to the Science 10 students through their elementary and junior high science courses. To help minimize this possibility (and thus improve confirmability of the results), specific interview questions were framed in such a way as to remind the students we were discussing either Science

10 or Physics 30AP class ***only*** and ***Neil*** as their teacher in an attempt to return focus to the class that was being studied, not other classes that had been experienced.

The number of classes observed and limited number of participants included in this study must also be considered limitations that, due to the researcher teaching full-time, were not easily avoided. The finding that there are some *missing* value manifestations may not mean that these values are not important to the participants. It is possible that their absence could be the result of not seeing enough classes (both in number and content coverage), interviewing enough students (other students would likely report different views of the class), and/or not interviewing students for long enough (which may be particularly relevant with the Science 10 students, as will be discussed in Chapter 4). Though Neil was very comfortable in front of his classes, and has even done extensive work in front of video cameras previously, there is always the potential that the mere act of recording could have affected how Neil communicated his values of science literacy.

Greater trustworthiness could also have been developed had more teachers been involved in the study. More participants could have enabled a wider range of classes, teacher experience levels, age, and sex to be observed to determine if other teachers modify their teaching of science literacy in similar or different ways to that of Neil. Involving more teachers and students in similar parallel studies could improve claims of transferability and dependability of the methods used to both collect and analyze the data obtained in this study.

With respect to the selected analytical framework, it is worth considering that the number of specific value categories under each domain is not equal (see Appendix B). In the modified framework that was used in this study, the “Human Values” domain had six categories, the “Cognitive Values” domain had only three categories, the “Process Values” domain had ten categories, and the “Societal Values” domain had only three categories. Researchers utilizing this framework should consider this discrepancy when coding to ensure that certain domains do not become “over counted” (and thus artificially over-valued) simply because there are more categories in which to code them.

Summary

This chapter described how the qualitative methods and analysis techniques selected for this investigation supported the exploration of science literacy values with minimal influence on or hindrance of emerging conversations about how the teacher presented his values in his classes.

CHAPTER 4: RESULTS AND DATA ANALYSIS

Introduction

This chapter will report the findings of the analysis of the data collected from coding of the transcripts of interviews of all participants and coding of the transcripts of all of the classes observed. First, a general comparison of frequency of codings across the value domains (Human, Cognitive, Process, and Societal) themselves will be provided to get a general sense of what domains of science literacy are professed to be of most importance to the teacher through interviews. The frequencies of these professed domains will then be compared to the frequencies of their manifestation in both the Science 10 and Physics 30AP classes and the frequencies of these domains in student interviews. Secondly, a more specific comparison of frequency of codings within each domain (that is, the values themselves) will be provided to see which specific values the teacher deems most important in interviews, which values manifest as being most important in class observations, and which values appear to be most clearly communicated and understood by students in their interviews.

General findings

From the data collected, a number of general statements can be made. Table 3 (on the following page) summarizes the number of coding references for domains and the data source from which the references are drawn. The final column of Table 3 (***Totals for all Sources***) shows the number and relative percentage of coding references for each of the value domains across ***all*** of the transcripts coded. This column shows that, of the four major domains, the Process Values domain was most often mentioned (≈43%) and that the Societal Values domain (≈5%) was least often mentioned across all data collected (interviews and class observations).

Table 3

Overview of Value Domains based on Their Frequency in Interviews and Class Observations

	Teacher Interviews	S10 Classes	P30AP Classes	S10 Student Interviews	P30AP Student Interviews	**TOTALS for all Sources**
Human	129 (18.2%)	267 (18.0%)	245 (22.5%)	28 (22.8%)	133 (48.7%)	**802 (21.2%)**
Cognitive	87 (12.3%)	291 (19.6%)	112 (10.3%)	1 (0.8%)	22 (8.1%)	**513 (14.0%)**
Process	321 (45.4%)	647 (43.7%)	502 (46.1%)	38 (30.9%)	58 (21.2%)	**1566 (42.6%)**
Societal	56 (7.9%)	44 (3.0%)	30 (2.8%)	25 (20.3%)	25 (9.2%)	**180 (4.9%)**
Facts of Science	110 (15.6%)	187 (12.6%)	192 (17.6%)	28 (22.8%)	34 (12.5%)	**551 (15.0%)**
OTHER	4 (0.6%)	45 (3.0%)	9 (0.8%)	3 (2.4%)	1 (0.4%)	**62 (1.7%)**
TOTALS	**707**	**1481**	**1090**	**123**	**273**	**3674**

Professed Teacher Science Literacy Value Domains

It is clear from the ***Teacher Interviews*** column that Neil had a broad view of science literacy, as all of the science literacy domains were evident in interviews with him. The data also suggest the most important domain for Neil in the teacher interviews is Process values (≈45%). This is not surprising given the following exchange in the first interview with him:

> ***Interviewer:*** *Definitely one of your key approaches, I think, would be getting into a lab and hands on…*
> ***Neil:*** *That's my mantra.*
> ***Interviewer:*** *(laughs) What's the mantra?*
> ***Neil:*** *Do labs…Get the kids out, you know…I had this [one class], you know, we're doing, we just started doing labs after labs and I think: 'This is fun', right?*
> ***Interviewer:*** *Hmm.*
> ***Neil:*** *And then near the end I said: 'Okay you guys, let's do another lab' and they just, as a group they just said: 'Just tell us the answer'. And I looked and I said: 'What, you've done too many labs?' and they said: 'Ya!' So I thought: good. So we've probably done enough, right? But, ya, I mean: you can't pretend science is empirical without experimenting.*

Societal values of science were the least frequently mentioned by Neil in interviews (≈8%), but were still volunteered as worth noting by him, which suggests this domain is still consciously part of Neil's teaching philosophy.

Different Manifestations of Values in Science 10 vs. Physics 30AP

The frequency of manifestations of value domains in classroom lectures, work, and laboratory experiences (***Sci10 Classes*** and ***P30AP Classes*** columns in Table 3) were numerically similar to their frequency of mention in Neil's interviews: process values were observed the most (≈44% in Science 10 classes, ≈46% in Physics 30AP classes), with societal values being observed the least (≈3% in both Science 10 and Physics 30AP classes). Despite these apparent similarities, however, there are differences in how the values within these domains were emphasized by Neil in class, which will be discussed below.

From the two ***Student Interview*** columns in Table 3, we can also see that the Science 10 students (Jack and Jill) valued "Facts of Science" (≈23%) more in the ***Science 10 Student Interviews*** than the teacher Neil did (≈16%), while Marie and Albert mentioned it slightly less in the ***Physics 30 AP Student Interviews*** (12.5%) than Neil did (≈16%). This fits well with the general findings in my own observations of the types of interaction Neil had with students in the two classes, which also made clear how apparent similarities in value manifestations can be misinterpreted in absence of context.

Based on my own notes and the full transcripts and video and audio recordings of the classroom and laboratory sessions, it was clear that Science 10 class times were used for establishing science rules, developing theoretical frameworks and using models, often through repetition. Consider the following quotations from Neil, and Jack and Jill (the Science 10 students):

> ***Neil:*** *You have to be able to write a chemical formula. And it takes, for most kids, 250 of 'em before they start to get them. So, you have to: I mean they have to do pages and pages of practice, you have to go over them, uh, and we, we did a bunch of pages of practice. Then, we wrote a quiz and some of them found out that they weren't – didn't know it yet because it's a lot more picky then they think. So, uh, they will have to…write another quiz and another quiz until at least they've got at least some pretty good, you know, skills that way. But there's no shortcut to being able to write a chemical formula (I-2).*
>
> ***Jack:*** *… basically my whole class learned pretty quick that if you don't know some formulas, you're not gonna get a good chunk of the final quiz. (I-2)*
>
> ***Jill:*** *Just, I don't know. Like all the important stuff he's, he, he really teaches us, he gets down to details…So I guess he'd want us to remember the details of it and he goes over it a lot, so, know the whole part. Like, not just parts of the subject or anything. (I-2)*

This makes sense as Science 10 is a foundational science course in high school, building a knowledge base for later science courses. As such, one *would* expect some emphasis on developing functional scientific literacy in students so they could become more "able" to become part of the scientific community. This was reinforced by the emphasis on accurate and consistent attainment and reporting of "Facts" as being valued by Jack and Jill in the ***Science 10 Student Interviews*** (≈23% of references). By mastering facts and logical "rules" of science, Jack and Jill reported feeling more confident as they began to be able to enter into science discussions. They learned to read, understand and utilize the language of science in class while being exposed to the dominant scientific models and theories. However, true to Neil's intentions, laboratory experiences were also used to apply and practice with those theories and models. It was clear Neil gave more direction in such activities during the Science 10 classes: there were few discussions about the ideas on *how* or *why* the science worked and more emphasis on developing skills by carrying out laboratory activities:

> ***Neil:*** *I like to get 'em into a lab within the first day or two, at the most. So, you know, we, we have a little chemistry murder mystery lab thing that, um, that we do. It's a white powders lab. It's at a junior high level: any junior high kid could do the same thing. And so, we present that to them, take 'em into the lab, and then you watch. You know, like, do these kids clean up after themselves? Do these kids get to work when they're working? Do they, do I have to tell them six times to put their eye- eyewear back on? Do, um, do they, do they screw up the chemicals when they use them, you know, kind of thing. Uh, do they come and ask me a million questions because they're afraid to do anything by themselves, that kind of stuff, and so...I could have told you right off the bat, within a day, that I've got some really weak writers. Um, that there's, there's an issue between what is an observation in a lab versus what is an inference, or a, a thing based on that. Uh, what needs to be presented as evidence, like a lot of them didn't know that. They knew the answer to the question…But they had no concept about, how, you know, what you would have to do. (I-2)*

In the Physics 30AP classroom sessions, Marie and Albert were also required to use their functional science literacy, but Neil took far more time to not only present models and theories but to intentionally present how the models and theories were developed, often with backing from mathematical proofs. There was a prevailing sense in the class that basic science understanding was implied by the teacher, which is valid in the sense that the Physics 30 AP students had succeeded in taking science to this point. However, the Physics students did not just learn about models and theories, they were also expected to understand how these models and theories came to be and to understand the limits of the models' and theories' effectiveness.

> ***Neil:*** *Well, I think with the Physics 30s, we have to because the curriculum moved to this "explain, explain, explain" level kind of thing, so, the, the work we did there was all about: "Okay, we're testing this model, this is what we think. Did this test, did this model hold up?" kind of thing.*

In the ***Physics 30 AP Student Interviews*** column of Table 3, Marie and Albert did report that the "facts" of science were of value (12.5% of references), but they clearly described science more as a human endeavour in their Physics 30AP student interviews (≈49%) than Jack and Jill did in their ***Science 10 Student Interviews*** (≈23%). This understanding of the Human aspect of science literacy is demonstrated in the following quotations:

> ***Albert:*** *Like the people who start the whole thing, that come up with these ingenious experiments…what caused them to think that way and that's how you, that's how I've started to come to answer these questions, not just: "What is the prompt and how quickly can I look this up on Google and answer the question", right? I think our society's kind of all about research, but I think that in, kind of understanding what the people were thinking when they were constructing the experiment and, uh, what they were looking for, I think that's important to, kind of, building that process of how to think and building those bridges to get to where you want.(I-2)*

> ***Marie:*** *…we're getting into labs now, just to help us understand everything and why it is the way it works and stuff…Which, I think a big part of labs is questionning it, 'cause if you just accept the theory, that's just: you don't really understand why it is that way…But if you question it, and experiment on it, you can figure out why it is the way it is. (I-2)*

Marie and Albert also described in their ***Physics 30AP Student Interviews*** how *ways* of thinking about and knowing the world (Cognitive domain: 8%) *are* part of science. When we compare this 8% with the 0.8% reporting of cognitive values from Jack and Jill's ***Science 10 Student Interviews*** in Table 3, we might suggest evidence of development in Marie and Albert in terms of more fully matured science literacy, particularly in light of Marie and Albert's comments about evaluating different models and theories of science through empiricism. This evaluation of the worth of various models was seen in the laboratory activities selected by Neil to engage the Physics 30AP students: rather than have them follow a procedure to expected conclusions (as was seen in the Science 10 laboratories), Marie and Albert had to develop their own procedures to produce data that could lead to the testing of theories. In the Physics 30AP lab experiences, there was less focus on "facts" of science as there was "practice" of science: testing models and theories that had been described in class.

Overall, the results demonstrate that, although one teacher may have a dominant attitude about what aspect of science literacy should have most emphasis (in this case, process values), it is still possible for that teacher to teach, represent, or model these values in different ways in different courses and/or streams ***and*** for his students to differentially interpret what is of value in the context of what they are experiencing in those different courses/streams.

Specific Findings

As previously seen, similarities in frequency of domain codings does not necessarily mean that the specific values in these domains are also the same between sources. For example, one interview may focus heavily on the "Curiousity" value in the Human domain, while another interview may have more examples of the "Student Confidence" value, but still show up as being rich in the Human domain. Appendix B has been included to break each of the domains down into their respective value categories to improve validity of more specific statements about the perceived values of different aspects of science literacy to the study participants. The percentages represented in Appendix B thus represent <u>percent of the specific value within its domain</u>, not within the total values coded as was seen in Table 3 (page 65). Tables 4 through 6 pull data from Appendix B to allow for more direct analyses of: (a) manifestations of the teacher's science literacy values; and (b) students' perceptions (and potential inculcation) of what is valued in their respective science classes.

Comparing Professed Teacher Values with Class Manifestations

In looking at the frequency of science literacy values in the Physics 30AP and Science 10 classes and comparing them to Neil's interviews (see Table 4 on the next page), we can consider whether the manifestations of Neil's science literacy values match his professed values. In some cases, we see the value frequencies match quite well, as would be expected if a teacher is authentically sharing the science literacy values he deems most important. However, in other cases discrepancies between the values are apparent and call for greater consideration of context.

Table 4

Comparison of Professed Teacher Values with Class Manifestations of Those Values

HUMAN VALUES	Teacher Interviews	P30AP classes/labs	S10 classes/labs
H1. Curiosity	22 (17.1%)	46 (18.8%)	49 (18.4%)
H2. Longing to know and understand	37 (28.7%)	66 (26.9%)	77 (28.8%)
H3. Open mindedness	17 (13.2%)	10 (4.1%)	15 (5.6%)
H4. Integrity	4 (3.1%)	4 (1.6%)	13 (4.9%)
H5. Creativity	13 (10.1%)	60 (24.5%)	49 (18.4%)
H6. Student Confidence in science	36 (27.9%)	59 (24.1%)	64 (24.0%)
TOTALS	**129**	**245**	**267**
COGNITIVE VALUES	Teacher	P30AP	S10
C1. Rationality	8 (9.2%)	57 (50.9%)	155 (53.3%)
C2. Search for Evidence	51 (58.6%)	38 (33.9%)	107 (36.8%)
C3. Skepticism	28 (32.2%)	17 (15.2%)	29 (10.0%)
TOTALS	**87**	**112**	**291**
PROCESS VALUES	Teacher	P30AP	S10
P1. Diversity in Scientific Thinking / Different forms of sci. inquiry	7 (2.2%)	19 (2.4%)	18 (2.8%)
P2. Empiricism	63 (19.6%)	51 (6.5%)	107 (16.5%)
P3. Parsimony	3 (0.9%)	3 (0.4%)	33 (5.1%)
P4. Science Community	44 (13.7%)	103 (13.2%)	109 (16.8%)
P5. Accuracy	19 (5.9%)	97 (12.4%)	117 (18.1%)
P6. Reliability	12 (3.7%)	8 (1.0%)	42 (6.5%)
P7. Valuing Process	94 (29.3%)	386 (49.4%)	95 (14.7%)
P8. Tentative Nature of Science	29 (9.0%)	26 (3.3%)	29 (4.5%)
P9. Validity	24 (7.5%)	6 (0.8%)	19 (2.9%)
P10. Developing Models	26 (8.1%)	83 (10.6%)	78 (12.1%)
TOTALS	**321**	**782**	**647**
SOCIETAL VALUES	Teacher	P30AP	S10
S1. Objectivity	9 (16.1%)	4 (13.3%)	30 (68.2%)
S2. Interdependence	27 (48.2%)	17 (56.7%)	6 (13.6%)
S3. Meaning making/Historical aspect of science	20 (35.7%)	9 (30.0%)	8 (18.2%)
TOTALS	**56**	**30**	**44**
ADDITIONAL VALUES	Teacher	P30AP	S10
F. Facts of Science	**110**	**192**	**187**
O. OTHER	**4**	**9**	**45**

Using Table 4, we can see that under the “Human Values” domain, the value of “Open mindedness” was mentioned more by Neil in ***Teacher Interviews*** (≈13%) than it was manifested in either of his ***Physics 30AP Classes/Labs*** (≈4%) or ***Science 10 Classes/Labs*** (≈6%). This could lead to a number of inferences: the small sample size of classes did not enable this value to show up; the teacher could be ensuring that the students were aware of only the dominant opinions of scientists relating to the subject matter, and/or the teacher is only stating a value that is not shared in classes. However, based on the context provided by direct observations of the classes and discussions with Neil, what is most likely is that Neil *values* openness of science, but did not want students to lose focus on the dominant views that represent the course content. The value "Creativity" had an opposite trend: Neil mentioned it less in ***Teacher Interviews*** (≈10%) than it was observed in his classes (≈25% of the coding references in ***Physics 30AP Classes/Labs*** and ≈18% in ***Science 10 Classes/Labs***). This is not too surprising as Neil is very fluid in his teaching style and moves quickly from idea to idea, often sharing impromptu stories of innovation and unique approaches to problems during class lectures.

Under the "Cognitive Values" domain in Table 4, there are more substantial differences. The most clear discrepancy arises in the "Rationality" value, where Neil rarely mentions this value in ***Teacher Interviews*** (≈9%), but it manifests in both his ***Physics 30AP Classes/Labs*** and ***Science 10 Classes/Labs*** with much higher frequencies of over 50%. In this case, many of the instances of "logic" coded in the class sessions were due to the approach taken by Neil in "constructing" the students' understanding of concepts in a logical way, thus demonstrating the value of logic and rationality through *modeling* rather than direct mention as a concept to be learned. This introduces an important consideration: the actions of the teacher in the class may model values the teacher does not intend, but could be seen as intentional by the students. As Neil clearly sees the scientific method as important, it is not a surprise that the values of "Search for Evidence" (≈59%) and "Skepticism" (≈32%) appear often in ***Teacher Interviews***, but also looking at Table 4 we can see these values are less obvious in class sessions

(“Evidence” at ≈34% for ***Physics 30AP Classes/Labs*** and ≈37% for ***Science 10 Classes/Labs***; “Skepticism” at ≈15% for ***Physics 30AP Classes/Labs*** and ≈10% for ***Science 10 Classes/Labs***). Taking these findings together, in the context of discussions with Neil and notes taken during class observation, these results can be reconciled by considering how Neil uses logic and rational arguments in his classes to teach skepticism of evidence itself. This was particularly true in the Physics 30AP classes, where students evaluated models and theories that were presented by systematically testing them.

In the “Process Values” domain, the two categories “Accuracy” and “Valuing Process” show the greatest frequency discrepancies between Neil’s interview and their manifestation in the class in Table 4. Neil did not spend much time discussing “accuracy” (≈6%) in ***Teacher Interviews***, yet it is clear that consistent and correct application of science concepts and “rules” is expected of students in both ***Physics 30AP Classes/Labs*** (≈12%) and ***Science 10 Classes/Labs*** (≈18%). Coding this value was interesting in that Neil’s interviews often focused on accuracy as a necessary skill to be acquired whereas in class it manifested as getting the “right” answers on assignments and tests. Thus, the manifestation of the value of accuracy in class teaching may reinforce a deep-seated notion within the students that they “must” learn the facts of science correctly, even if the teacher professes that “science facts” only have value as far as they can be used in arriving at consensual conclusions from data. As students are very conscious of their marks, it is not surprising that accuracy and “taking up” past assignments and lab reports may take up more time in classes than a teacher might be aware of. With regards to “Valuing Process,” we see in Table 4 that this is very important in the ***Physics 30AP Classes/Labs*** (≈49%), but less so in the ***Teacher***

Interviews (≈29%) and ***Science 10 Classes/Labs*** (≈15%). It has already been mentioned that the Physics students were expected to carry out evaluation of scientific ideas in class and during labs, so the high value for "method" in this group is not surprising, especially when one considers that Physics 30AP students were required to learn the "facts" and "theories" of the course on their own, outside of class time, allowing more time to devote to practicing the science rather than learning about it. The lower value for the Science 10 class in Table 4 represents the opposite of this: Neil clearly took large amounts of class time ensuring that students worked through basic concepts, often through repetition of key concepts on worksheets and discussions about quiz and test results, before they entered the lab. In both cases, the lab exercises added to the learning in the class, but with different intentions. The inquiry process that occurred in Physics 30 AP classes and labs incorporated more aspects of the scientific method than Science 10 experiences did.

Under the "Societal Values" domain in Table 4, discrepancies occurred in all three categories. With respect to the "Objectivity" value, the ***Science 10 Classes/Labs*** showed much higher emphasis on this value (≈68%) than either the ***Teacher Interviews*** (≈16%) or the ***Physics 30AP Classes/Labs*** (≈13%). In contrast, the opposite was true of the "Historical Aspects" value, where manifestations were lower in the ***Science 10 Classes/Labs*** (≈18%) than in ***Physics 30AP Classes/Labs*** (≈30%) and the ***Teacher Interviews*** (≈36%). This mostly related to the importance given to the singular correctness of certain responses in Science 10 class discussions and on class assessments when learning new concepts. It is worth noting that the interviews with Neil did not suggest that "getting the one right answer" was by any means the most important value: rather, Neil mentioned numerous times that in order to reach higher levels of science literacy, students did need a certain degree of objective knowledge about core science conventions and the process of science in order to question it. In Science 10 classes, this focus on gaining fundamental science skills often came off as suggesting that science knowledge was based on fact and not opinion or personal bias for one model over another. This was not the case in the Physics 30AP classes, where Neil continually challenged the students to consider how models may not be as accurate as some might think and even to consider the danger of one scientist holding too much influence over others. The objectivity of science was acknowledged as being of value to "knowing" something scientifically in the Physics 30AP classes, but it was clear that Neil was not espousing it as an absolute characteristic of science. With respect to the third Human value of "Interdependence," it is clear again in Table 4 that the ***Science 10 Classes/Labs*** were focused more on learning discrete content and concepts (only ≈14% mention of science factors that influence each other and their environment) compared to the ***Teacher Interviews*** (≈48%) and ***Physics 30AP Classes/Labs*** (≈57%). It was clear that Neil expected the Physics students to bring more of their past learning and experiences in Physics units and classes into discussions and, as a result, more connections amongst these ideas was fostered. As mentioned by Neil in interviews, one aspect of importance in a Science 10 class is ensuring that all students gain mastery of key concepts. As students come from many different former schools, their experiences coming into Science 10 are varied and developing a core set of skills may be more time-consuming than for a class of students who have been together for two or three years at the same school (as is the case for the Physics students). There is potential for "opening" discussion in the Science 10 classes to incorporate these diverse experiences to foster the value of interdependence, but the risk of not attaining mastery of concepts and content required for the next round of science courses must be considered. As Science 10 is a general introductory science course leading to not only higher general science courses (Science 20 and 30), but also to discipline specific studies in Biology, Chemistry, and Physics, discussion of interdependence of science in and amongst these specific fields may be left to later courses at the 20- and 30-levels.

Comparing Class Value Manifestations with Student Perceptions

The results of the coding of the various values for the student interviews is given in Tables 5 and 6, which allow for comparisons of Neil's delivery of science values in classes with the students' perceptions of science values in these classes. Put another way, while the comparison of the teacher interview values frequencies with class manifestation values frequencies (Table 4) enabled a consideration of *delivery* of those values *by the teacher* in the previous section, comparison of the student interview values frequencies with class manifestation values frequencies (Tables 5 and 6) enable a consideration of *acceptance/inculcation* of those values *by the students*.

Physics 30AP Comparisons.

Table 5

Comparison of Class Value Manifestations with Student Perceptions of Those Values in a Physics 30AP Class

HUMAN VALUES	Physics 30AP classes/labs	Physics Student Interviews
H1. Curiosity	46 (18.8%)	32 (24.1%)
H2. Longing to know and understand	66 (26.9%)	74 (55.6%)
H3. Open mindedness	10 (4.1%)	1 (0.8%)
H4. Integrity	4 (1.6%)	1 (0.8%)
H5. Creativity	60 (24.5%)	3 (2.3%)
H6. Student Confidence in science	59 (24.1%)	22 (16.5%)
TOTALS	**245**	**133**
COGNITIVE VALUES	Physics 30AP classes/labs	Physics Student Interviews
C1. Rationality	57 (50.9%)	2 (9.1%)
C2. Search for Evidence	38 (33.9%)	9 (40.9%)
C3. Skepticism	17 (15.2%)	11 (50.0%)
TOTALS	**112**	**22**
PROCESS VALUES	Physics 30AP classes/labs	Physics Student Interviews
P1. Diversity in Scientific Thinking / Different forms of sci. inquiry	19 (2.4%)	1 (1.7%)
P2. Empiricism	51 (6.5%)	15 (25.9%)
P3. Parsimony	3 (0.4%)	0
P4. Science Community	103 (13.2%)	12 (20.7%)
P5. Accuracy	97 (12.4%)	4 (6.9%)
P6. Reliability	8 (1.0%)	1 (1.7%)
P7. Valuing Process	386 (49.4%)	24 (41.4%)
P8. Tentative Nature of Science	26 (3.3%)	0
P9. Validity	6 (0.8%)	1 (1.7%)
P10. Developing Models	83 (10.6%)	0
TOTALS	**782**	**58**
SOCIETAL VALUES	Physics 30AP classes/labs	Physics Student Interviews
S1. Objectivity	4 (13.3%)	0
S2. Interdependence	17 (56.7%)	21 (84.0%)
S3. Meaning making/Historical aspect of science	9 (30.0%)	4 (16.0%)
TOTALS	**30**	**25**
ADDITIONAL VALUES	Physics 30AP classes/labs	Physics Student Interviews
F. Facts of Science	**192**	**34**
O. OTHER	**9**	**1**

The frequencies of values between the ***Physics 30AP Student Interviews*** and ***Physics 30AP Classes/Labs*** observations seen in Table 5 are more similar to each other than the frequencies of values between the ***Science 10 Student Interviews*** and ***Science 10 Classes/Labs*** observations. This may represent differences in the motivations of the students in taking each of the respective courses. Science 10 is a science course that most high school students could take (Jack and Jill are only beginning the climb), while Physics 30AP is a course taken by fewer students, most of whom would pursue Physics or Mathematics at the post-secondary level (Marie and Albert had already experienced science success and were looking for the next challenge). That said, it may be expected that Marie and Albert would be very focused on what is being taught in the Physics classes to ensure they are matching the teacher's expectations. Jack and Jill may not be as focused on the meaning of the course for them, seeing it more as a stepping stone to complete credit requirements and to proceed to any number of 20-level science courses.

There are a few discrepancies worth discussing in the Table 5 Physics 30AP coding frequencies. In the Human Values domain, Marie and Albert's ***Physics 30AP Student Interviews*** valued "longing to know and understand" higher (≈56%) than it was presented in ***Physics 30AP Classes/Labs*** (≈27%). This may again be due to the intention of the students: their own desire to "know and understand" the science in the class may be much higher than what Neil presented in class, which could be expected in a highly academic and self-motivated class such as this. The results for the "Creativity" value (≈2% for the ***Physics 30AP Student Interviews*** and ≈25% for the ***Physics 30AP Classes/Labs***) may reinforce this interpretation: Marie and Albert may be focused more on doing well in the course than on solving problems creatively, and thus see this value as less important in understanding science.

In the Cognitive Values domain of Table 5, we see a similar result in the "rationality" value (***Physics 30AP Student Interviews*** ≈ 9%; ***Physics 30AP Classes/Labs*** ≈ 51%): Marie and Albert are clearly exposed to the process of rational thought in the class and lab activities, but do not report it as a key value in science literacy. On the other hand, Marie and Albert report a higher level of the "skepticism" value (≈ 50% in ***Physics 30AP Student Interviews***) than seen in the ***Physics 30AP Classes/Labs*** (≈ 15%). Whether the students have picked this up from other science classes (either in unobserved Physics 30AP classes or other courses) is unknown, but it is clear that this value was considered by them to be an important trait for scientifically literate students to have.

In the Process Skills domain of Table 5, the value coding frequencies matched up quite well, with "empiricism" and "developing models" showing the greatest divergence. The value of empiricism was regarded more highly by Marie and Albert in their ***Physics 30AP Student Interviews*** (≈26%) than it was seen in ***Physics 30AP Classes/Labs*** (6.5%). However, this could very well be due to the fact that only four classes were observed. Both Marie and Albert did mention in their interviews that more labs had been done earlier in the year than they were doing in the observation period and more labs were expected after they had written their AP Physics exam. The value of developing models showed only in the ***Physics 30AP Classes/Labs*** (≈11%) and not at all in Marie and Albert's interviews. However, the students *did* mention *comparing* and *testing* models in their interviews, so this may imply that they were also learning about how those models were developed in class. Even so, Marie and Albert clearly expressed enjoyment at the ability to evaluate models rather than just learn about them.

The Physics 30AP interview and class manifestation data for the Societal Values domain showed the least congruence in value frequencies of any of the domains in Table 5. However, it is worth mentioning that the Societal Values domain was also the least evident in both of Neil's interviews, which may mean that the students may be reporting experiences in other science classes they had taken. The "objectivity" value was not mentioned by Marie and Albert in interviews, though it was observed (≈13%) in ***Physics 30AP Classes/Labs***. The fact that the entire domain itself had the lowest coding frequency of all value domains mentioned by Neil in ***Teacher Interviews*** (≈8%, Table 3) and observed in ***Physics 30AP Classes/Labs*** (≈3%, Table 3) makes the absence of this value in Marie and Albert's interviews more understandable as they would have been exposed to it less frequently. The results for the "interdependence" and "historical aspect of science" values cannot be explained away so easily, however. Interdependence was mentioned in Marie and Albert's ***Physics 30AP Student Interviews*** as a societal value more often (≈84%, Table 5) than it was observed in the ***Physics 30AP Classes/Labs*** (≈57%, Table 5). This may suggest (as was apparent in Albert's interview) that they are also reporting on what they have learned in other classes. Thus, interdependence amongst science classes needs to be considered as a part of their "whole school" experience when comparing student perceptions of literacy with class manifestations. The "historical" value in Table 5 is different. In ***Physics 30AP Classes/Labs***, this value was expressed as a societal science value approximately 30% of the time, while it was less obvious in Marie and Albert's ***Physics 30AP Student Interviews*** (≈16%). One possible reason for this is that the students are focusing more on the results of scientists' work (that is, the current and prevailing model or theory) to earn marks on exams than on the processes and personalities leading to the currently accepted model or theory under study. This does not mean that the history was ignored, however. In discussions and interviews, both Marie and Albert clearly shared how much they enjoyed learning about the "stories and people" behind the discoveries.

Finally, it is worth noting that though "facts of science" were clearly valued and delivered by Neil in the ***Physics 30AP Classes/Labs***, appearing 192 times in the coding of the class transcripts (see Table 5), Marie and Albert did not report "facts" of science as being as important (only mentioned 34 times in ***Physics 30AP Student Interviews***). This difference was explained by Neil in many discussions: he clearly expected students at the 30AP level to be responsible for learning these facts on their own.

Science 10 Comparisons.

The results of the analyses of the differences in value frequencies across all of the value domains for the ***Science 10 Classes/Labs*** and ***Science 10 Student Interviews*** (Table 6) are not as immediately informative as the Physics 30AP results. For example, in Table 6 we can see that all values in each of the Human Qualities (with the exception of curiousity), Cognitive Dimension, and Societal Dimension domains vary by 5% or more. There is more agreement as to the Science as Process values, but these also show some discrepancies in the empiricism, accuracy, and valuing process categories.

Table 6 ***Comparison of Class Value Manifestations with Student Perceptions of Those Values in a Science 10 Class***		
HUMAN VALUES	Science 10 classes/labs	Science 10 Student Interviews
H1. Curiosity	49 (18.4%)	1 (3.6%)
H2. Longing to know and understand	77 (28.8%)	9 (32.1%)
H3. Open mindedness	15 (5.6%)	3 (10.7%)
H4. Integrity	13 (4.9%)	0
H5. Creativity	49 (18.4%)	0
H6. Student Confidence in science	64 (24.0%)	15 (53.6%)
TOTALS	**267**	**28**
COGNITIVE VALUES	Science 10 classes/labs	Science 10 Student Interviews
C1. Rationality	155 (53.3%)	0
C2. Search for Evidence	107 (36.8%)	1 (100%)
C3. Skepticism	29 (10.0%)	0
TOTALS	**291**	**1**
PROCESS VALUES	Science 10 classes/labs	Science 10 Student Interviews
P1. Diversity in Scientific Thinking / Different forms of sci. inquiry	18 (2.8%)	2 (5.3%)
P2. Empiricism	107 (16.5%)	3 (7.9%)
P3. Parsimony	33 (5.1%)	0
P4. Science Community	109 (16.8%)	8 (21.1%)
P5. Accuracy	117 (18.1%)	3 (7.9%)
P6. Reliability	42 (6.5%)	1 (2.6%)
P7. Valuing Process	95 (14.7%)	15 (39.5%)
P8. Tentative Nature of Science	29 (4.5%)	1 (2.6%)
P9. Validity	19 (2.9%)	1 (2.6%)
P10. Developing Models	78 (12.1%)	4 (10.5%)
TOTALS	**647**	**38**
SOCIETAL VALUES	Science 10 classes/labs	Science 10 Student Interviews
S1. Objectivity	30 (68.2%)	0
S2. Interdependence	6 (13.6%)	24 (96.0%)
S3. Meaning making/Historical aspect of science	8 (18.2%)	1 (4.0%)
TOTALS	**44**	**25**
ADDITIONAL VALUES	S10	S10 I
F. Facts of Science	**187**	**28**
O. OTHER	**45**	**3**

As a whole, these discrepancies can, in part, be attributed to the dearth of fully explained responses collected in Jack and Jill's interviews. Both of these participants volunteered fewer comments about their class experiences than the Physics 30AP students did. Although the time with both the Physics and Science students during interviews was limited, this time limitation became far more restrictive in extracting commentary from – and establishing dialogue with – Jack and Jill, who were also clearly more reticent. This was reflected in the quality and shortness of their responses and the number of coded references for the ***Science 10 Student Interviews*** in Table 6: only 28 instances of Human value references – compared to 129 for the ***Teacher Interviews*** (Table 4) and 133 for the ***Physics 30AP Student Interviews*** (Table 5); 1 instance of Cognitive value reference in Table 6 – compared to 87 for the ***Teacher Interviews*** (Table 4) and 22 for the ***Physics 30AP Student Interviews*** (Table 5); 38 instances of Process value references (Table 6) – compared to 321 for the ***Teacher Interviews*** (Table 4) and 58 for the ***Physics 30AP Student Interviews*** (Table 5); and 25 instances of Societal value references (Table 6) – compared to 56 for the ***Teacher Interviews*** (Table 4) and 25 for the ***Physics 30AP Student Interviews*** (Table 5). In total, the values in the Science 10 student interviews were coded in less than half as many instances as values in the Physics 30AP student interviews. This makes it unclear whether Jack and Jill truly did not perceive the importance of certain values that were delivered by Neil or they were unsure how to talk about their experiences and understanding of these values as being important to science. As a result, any interpretations listed here must be considered in the context of this small number of interview references being compared with what was seen in class.

One thing was very clear in the Science 10 student interviews with Jack and Jill: they felt that one of the most important aspects of being a "good" science student was to use the specific conventions and wording of science correctly. As they were completing a unit on chemical nomenclature, this is not surprising. When one looks at the transcripts of the interviews, the focus on language use and getting "good" results (that is: *expected* results) on lab activities were the ways Jack and Jill saw themselves as proficient in science, which was their general perception of science literacy. The highest mentions of values in each domain reflect the desire of Jack and Jill to do well in class. In the Human domain of Table 6, the "student confidence" value (≈ 54%) was the highest in the ***Science 10 Student Interviews*** and the coded statements were related to Jack and Jill describing how they use assignments and quizzes to "do better" on subsequent tasks. In the Cognitive domain, the only mention in the ***Science 10 Student Interviews*** was for the "evidence" value, which again was related to making sure that the correct answer was determined for a laboratory activity. In the Process domain of Table 6, "valuing process" was the highest coding in the ***Science 10 Student Interviews*** at ≈ 40%, which focused mostly on "doing" labs to show that they "knew" what they were doing – again, the focus was on getting the right answer, not so much the process of engaging in the activity itself. Finally, in the Societal domain of Table 6, the "interdependence" value (≈ 96% in ***Science 10 Student Interviews***) was of most value to Jack and Jill as they both felt they should be able to apply their knowledge to "real-life" situations and/or future careers. This shows, perhaps, the most long-term consequences for Jack and Jill in becoming "scientifically literate." It is worth mentioning, however, that there was little mention of interdependence outside of personal benefits from science.

Summary

It is no surprise that the data clearly demonstrated the many ways in which science literacy can be interpreted by both teachers and students. Ambiguity in the meaning of science literacy itself has plagued researchers for decades and this could lead some teachers to feel discouraged in their ability to "teach" what science literacy means, especially if they have traditionally found success in teaching only the content of science programs of study. However, the results should not be disregarded as being unable to clearly define science literacy, but rather should be used to increase appreciation amongst educators for the role they play in promoting the full-range of the scientific experience. It is clear that what teachers believe about science and what they share about those beliefs has an impact on the students in their charge, regardless of the level at which it is presented, in ways that we may never assess in a classroom. Science literacy involves a commitment to science appreciation, not just the teaching of a memorizable phrase or definition of literacy. As a result, growth of science literacy need not be quantified through assessment, but can instead be appreciated as a process of developing greater appreciation of science literacy's many aspects by both the teacher and student. In this sense, we can see that considering the many values that build towards science literacy (and considering why we value some over others) can indeed play a role in the development of students and teachers in all streams of science education.

CHAPTER 5: DISCUSSION AND CONCLUSIONS

Introduction

The final chapter will follow the order of analyses discussed in Chapter 4, synthesizing findings from each to reach a conclusion with respect to the original research question. A review of the methods, in light of the research findings, will then be presented to demonstrate the role that each method played in supporting an answer to the question. After this, implications and benefits of the research findings will be shared, which will then lead into suggestions for further research. Finally, concluding remarks and a personal reflection will be provided to support and encourage ongoing work in this area and to demonstrate how it can legitimize the importance of the choices teachers make on a daily basis when teaching science.

Revisiting the Research Question

To answer the research question – "To what extent are a teacher's professed values of science literacy communicated to and understood by students in different classroom contexts?" – specific findings of science literacy value frequencies in Chapter 4 will be considered in turn.

Clarifying the Teacher's Professed Science Literacy Values

When Neil was first asked what "science literacy" meant, he answered in the following way:

> ***Neil****: I think the biggest thing it means is it's a world view where you think about what's going on, and why, and you experiment to find out if you're right. So, the scientific method. Um, that's, I think, the number one thing. So if you watch a show like "The MythBusters," they're not that scientific, not really, but the world view they're presenting is: let's test it and see if it's gonna work, kind of thing…and for most of the kids, if that's all they ever get and they develop a little bit of skepticism about, well: 'You say this, but I'm gonna try it and see,'*

then I think, you know, that's great for most of us. So, now, as secondary to that, the scientific method, you can formalize that with big words or small words, or whatever you want to do, and we have curricula that tells us we have to do that kind of thing. And then there's also a body of knowledge that we've learned as a result of the scientific method, and that's part and parcel of scientific literacy as well. So it's sort of those three things I think.

Through the entire study, it was clear that use of the "scientific method" (process literacy) remained a very important value for Neil. It was also clear that Neil did not define science literacy in a singularly *functional* way: that is, memorizing of facts and being able to read and write scientifically. This suggests that teachers such as Neil may have a broader understanding of the nature of science (as described in Chapter 1) and can see science literacy as representing a spectrum of values. Sharing this with other teachers who may not have taken the time to consider their own definitions of science literacy will be crucial if we wish to see teachers *consciously* teaching their own values while remaining open to the addition of other literacy values.

Comparing Professed Teacher Values with Class Manifestations

The next step in analysis was to determine if Neil's professed values were manifested in his Science 10 and Physics 30AP classes. As mentioned in Chapter 4, Neil was observed a total of eight times in this study (four full Science 10 classes and four full Physics 30AP classes) and he clearly and proportionately demonstrated the values of science literacy that were espoused in his interviews. As Neil's professed view of science literacy was heavily focused on the value of scientific process (via the scientific method and "doing labs"), it was not a surprise to see he addressed many of same science literacy values in classes through preparation for and performance of laboratory tasks. This is not to suggest that this is the only way to develop student science literacy, but *for*

Neil it was an authentic way. Not all of the science literacy values coded in this study showed equal weighting, but the values that Neil most described were well-represented in the classroom. A potential science teaching pitfall is exposed here: choosing only one strategy (such as performing labs) to "teach" science literacy (in this case, the "Process" Domain) could preclude teaching and discussion in class to address the full spectrum of science literacy. That is to say, if a teacher does not mindfully incorporate a range of science literacy values in his or her teaching, that teacher misses an opportunity to share these values with students. In this study, I would argue that did not happen – Neil did use many other methods to introduce many aspects of science literacy – but the results do suggest that lower rated values could be used as stimulus material to facilitate a deeper, more directed self-reflection. This was acknowledged by Neil in the second interview:

> ***Neil****: Well, the questions having to do with science literacy, they're always sort of lurking in the background. So, I think the discussions we're having are just sort of bringing those things a little bit closer to the surface: what is it that kids are supposed to get out of these?*

The value of the self-reflection experienced in the study was also reinforced in the second and final interviews, when Neil discussed how the study made him think about how he presents science to his students:

> ***Neil:*** *You know…I've seen, in my 'years of teaching', I've seen all kinds of ideas come out and I'll look at them and I'll think: 'That might be a good idea', and I'll try it. And if it works, I'll try it again. If it doesn't work, well, it still might be a good idea for somebody else.* (second interview)

> ***Neil****: Well, it's like any time you talk to somebody about ideas. Right? How I talk about things is always sort of couched in terms of everything else you do. So, you start off as: 'This is what it is, this is what it is.' And then: 'Well, this is maybe what it is or this is a model of this.' And so, I'm moving towards just: the language in the back that you talk to the kids... the language is a little different…like I said, the more we internalize that, in the way we speak to kids, the easier it is for the kids to sort of follow*

through and pick up on that stuff. (final interview)

It is clear from the classroom observations and discussions with Neil that not only has he taken the presentation of his values seriously, he has also taken seriously the reflection on his method of teaching these values and has kept himself open to others' ideas that could improve his own teaching.

Comparing Class Value Manifestations with Student Perceptions

The next step in analysis was to determine if the manifestations of Neil's science literacy values matched the perceptions of science literacy values reported by the students in their interviews. From Jack and Jill's Science 10 interviews, we can see science literacy being associated with "getting the right answer" and knowing how to use the language of science correctly. In the first round of interviews, this was seen by the Science 10 students as the main aspect of being scientifically literate, and remained so throughout the study. However, due to Neil's clear emphasis on the importance of laboratory activities, proficiency in the use of scientific method did begin to take on greater relevance to Jack or Jill in the second interview, seemingly expanding their views of what makes a science student literate. It would be presumptuous to say, however, that "doing science" replaced their shared view that "knowing science" was still of most value. Consider the following quote from Jill when she was asked in the second interview how a teacher could help build a student's science literacy:

> ***Jill****: I would...well, I'd start by making sure that...I'd start with notes, and making sure they got it down, and got, like, a beginning of the concept… And then I think I'd move onto a lab to demonstrate it and show how they'd use it. And then, I'd do tests, just to see if they, they've memorized it, kind of thing, and got it in their brain. And then if they didn't do too good on the test, I'd go back to explanations and do more to get it.*

Although scientific method was becoming more important to her as a science skill, Jill still felt that "knowledge" of "correct" science would be the indicator that students were more science literate. We can see a similar perception with Jack when asked the question: "What would you say your teacher would say is the most important thing for you to remember from science class?" during his second interview. This was his response:

> ***Jack**: Remember all the formulas…Because, basically my whole class learned pretty quick that if you don't know some formulas, you're not gonna get a good chunk of the final quiz.*

Jack and Jill became more aware of the importance of scientific conventions and the scientific method, but the "facts" of science were still highly valued by them and were the means by which they judged their own literacy attainment.

In Marie's and Albert's Physics 30AP interviews, the students seemed to move beyond "knowing science" to being able to question it. When asked what they felt the most important thing to know about science was, they answered in the following ways.

> ***Marie**: I would say to question things... and wonder why things happen.*
> ***Interviewer**: Alright. And what leads you to that statement?*
> ***Marie**: Well, because if you don't wonder why things happen, you'll never learn anything more, and you'll never get any further with your understanding of anything.*
> ***Interviewer**: Okay. So, in class did you find yourself experiencing that? Like, you wanted to know a bit more once you'd learned a little bit.*
> ***Marie**: Mm hmm. For sure.*
> ***Interviewer**: Can you think of some examples?*
> ***Marie**: Um, well, I think, like in physics, one of the newest things we've, we're doing, like, some really, quantum crazy stuff that's like, it's really kinda weird how it works. So, it's like, how does that go further and how does that actually apply to everyday life and stuff.*
>
> ***Albert**: I think everything we've learned so far has prepared me for university…There's some things I'll, I've learned I will never use again but, honestly, I don't mind that. Like,I know a lot of students they just*

> *want to know what's being tested, and what's, important, and useful in life. But, I think that, just an overall knowledge is better, even if you don't get tested on it, because it's not: Like, school, I think, school and life, it's not just about knowing how to answer tests, it's how to be more educated…And, as a result, AP, I mean, there's a whole lot…of stuff that isn't always tested…So there's a lot of things that they give you, they teach you, that isn't always tested, but that's, uh, you know what? You're just more educated for the future. And the more you know, the further you go, so I can't really see why anyone would be opposed to taking more, unless they weren't, uh, capable of learning that.*

From these two responses, we can see Marie and Albert have begun to *apply* their knowledge in a way that is of value *to them*, with less regard to (or at least less mention of) the marks they have to earn. We can also see both students beginning to *evaluate* the importance of what they have learned. Neither student denied that "knowing" science facts was important, but both were more aware of their own ability – and even responsibility – to question what they were learning.

Finally, from Neil's perspective, we have already shown that he believed science literacy *must* include empirical experiences. It also became clear during member-checking discussions and later interviews that Neil believed there was a danger with how students could incorrectly perceive "science literacy" by focusing on the words themselves and envisioning the statement as describing *only* the functional skills of reading and writing scientifically.

Comparing Physics 30AP and Science 10 Science Literacy Values

As Neil's teaching was observed in both a Science 10 (general and introductory) class and a Physics 30AP (college-credit and relatively exclusive) class, it was possible to consider how the manifestation and acceptance of Neil's science literacy values were affected by the context of two very different groups of students. Based on the results of the classroom observations, discussions and interviews with Neil and interviews with the students, it can be said that, although Neil clearly preferred the same teaching *strategy* (discussion and use of the scientific method, laboratory experiences) in both classes, the emphasis on “scientific method” *was* contextualized differently for the two classes. The Science 10 students (Jack and Jill) were taught the basic science principles and facts enabling them to achieve success in labs, empirically supporting the theoretical concepts and ideas they had been taught in class. Time in the Science 10 classes was also devoted to helping students meet high school expectations and gain confidence in high school science through repetition to mastery. Neil acknowledged this in the first and second interviews when discussing the challenges he saw with the Science 10 students:

> ***Neil:*** *Grade Tens, the first, I mean, with weaker kids, it’s the first five months of high school that we have to turn ‘em into high school students* (first interview).
>
> ***Neil****: I could have told you right off the bat, within a day, that I’ve got some really weak writers. Um, that there's, there's an issue between what is an observation in a lab versus what is an inference, or a, a thing based on that. Uh, what needs to be presented as evidence, like a lot of them didn’t know that. They knew the answer to the question….But they had no concept about, how, you know, what you would have to do* (second interview).

The Physics 30AP students (Marie and Albert) were expected to know the basic science principles and facts before hand, often through self-study at home, and used the laboratory time to *test* models and, often, to experience failure in their own (and others’) designs and procedures to evaluate and improve them. While Jack and Jill performed structured lab activities that were complementary to what they had learned, Marie and Albert more often challenged the ideas they were taught in class: rather than supporting the theoretical knowledge, the Physics students were challenging it, testing it, seeing if empirically those ideas were valid. This shift may seem subtle to some, but consider the outcome: Jack and Jill were learning the same material in a different way, strengthening their knowledge of the canon of science and, while Marie and Albert certainly did this in class too, their lab activities were just as likely to lead them to challenge what they had been taught. This certainly shows a potential progression through literacy from Science 10 to Physics 30AP that Neil clearly utilized in his approaches to both classes: the manifestation of what Neil saw as important for science literacy (use of laboratory experiences) was indeed contextualized.

With these findings in mind, we can begin to address the research question in this study: "To what extent are a teacher's professed values of science literacy communicated to and understood by students in different classroom contexts?" The answer to the question, based on this study, is that a teacher who can clearly explain his or her understanding of science literacy *is* likely to demonstrate those values in his or her interactions with classes, and these demonstrations *do* have an effect on the students in that teacher's class. The teacher may emphasize or scaffold the delivery of these values differently in different classes. For example, Neil's dominant process skills literacy values can be espoused by using laboratory exercises to supplement and reinforce basic learning (Neil's Science 10 class) or by using laboratory exercises to question and evaluate different models (Neil's Physics 30AP class). Neil's dominant, or core, values did not change. In fact, in different classes, the differential manifestation of these values serves a very important purpose: furthering student confidence and enriching students' ability to engage in scientific dialogue starting from the points they are at.

The findings of this study also suggest that the degree to which the students *accept* these values as being *relevant* to their learning will determine whether the students develop more fully the type of science literacy the teacher is promoting in the class. This aspect of the question is more difficult to answer based on the values collected as student motivation for taking each class was not a key part of this investigation.

Review of Methods

The qualitative approach selected for this study allowed for openness to let all of the participants in the study to communicate their unique perspectives of science literacy. Though data were compared in terms of numbers and percentages of certain coded values, this was not intended to be a quantitative study as these frequencies could certainly change for the students and teacher in different contexts, making absolute statements based on these frequencies invalid. The frequencies of values for different teachers are not being compared here: rather, one teacher's professed values were compared to the manifestation of those values in his class.

The exploratory approach of the semi-structured interviews and member-checking discussions allowed for rich descriptions to emerge, as participants were able to express, in their own terms, what they felt they were experiencing in the science classes. As the study progressed, it was clear that – even with the same teacher – the two class sections that were observed (Science 10 and Physics 30AP) did have different "cultures of learning" beyond the content of the courses and these contexts shaped the teacher's and students' perceptions of what was of most value to them.

The comparison of values in the teacher and student interviews was very useful. The teacher interviews allowed for a candid discussion of the teacher's science literacy values so their manifestation frequency had a basis for comparison. The student interviews allowed for a consideration of how much the teacher's views (through teaching choices) could impact the students' perception of what is of value in science. In both cases, the contributions given by the participants through interviews added richness to and interpretive consistency with the class observations.

The time between student interviews (one month for the Science 10 students, who were in a semestered class; and six months for the Physics 30AP students, who were in a full-year class) allowed mid-way observations of each of the classes and time for students to be exposed to the values of the teacher, although it could be said that the time between interviews for the Science 10 students could have been increased to perhaps allow for more change and/or growth to become apparent. The timing of the three teacher interviews (first, before all student interviews; second, after two weeks; and third, near the end of the course) allowed for time to member-check and discuss preliminary findings with the teacher and time to use portions of the transcripts of student interviews in the later interviews. By utilizing the student interviews in this way, findings in this study were developed with the teacher, rather than in isolation from the teacher, which would have stripped away a layer of context in the students' responses and forfeited a chance for the teacher to learn from the students.

Classroom observations were essential in this study as they allowed for evidence of manifestations of the teacher's science literacy values and provided a clear view of what the students were being exposed to in each class. All of the tools used to record observations (field notes, video and audio recordings) proved valuable at different times. For example, the video tape enabled me to consider non-verbal cues given by the teacher when stressing a concept or dealing with student questions. The audio recording allowed for the teacher to carry the recorder with him, allowing the transcription of conversations that could not be heard on the video camera as he wandered from group to group in laboratory settings. The field notes were essential for developing initial inferences and formulating questions about my observations and could be used in this way due to the accuracy of transcription enabled by the two other recording tools (audio and video). As a whole, these tools captured a rich description of the context in which the participants were involved.

Member-checking was a very satisfying part of this research. Talking about my findings with the participants not only engaged them in the process more and allowed me to more accurately reflect their meanings, it also provided me with a renewed sense of confidence regarding the impact that collegial conversations can have on the teaching process. This, in turn, demonstrates the potential impact that sharing the results of this study could have on other educators in examining their own perceptions of science literacy.

Benefits of the Research

To the Teachers and Students Involved in the Study

According to Hostetler (2005), ethical research is more than just good intentions: the researcher must consider what happens to the participants of the study. Part of science literacy could be described as the ability to understand the process by which scholarly research is conducted in order to make good decisions about the validity and reliability of science findings for one's own life. The teacher and students involved in this study gained first-hand experience with the planning and carrying out of formal research and were encouraged through discussions to explore a wider scope of science education through the experiences and findings of the researcher.

As Ratcliffe et al. (2005) conclude: “Those teachers with first-hand experience of a research culture seem better able to view professional practice through an ‘evidence-informed’ lens, bringing their understanding of research to bear if their professional context allows” (p. 183). The teacher participant, Neil, expressed appreciation for the opportunity to refine and discuss teaching strategies without the stress of formal evaluation and in a way that did not focus on the performance of his students on science content assessments.

Student participants gained greater awareness of their own learning process by considering what they attended to in class and why they felt Neil was doing what he was doing. Students also had the opportunity to provide feedback on their own learning as they saw it happening. In one case, the self-reflection made Albert realize how much he would like to go back through science again:

> ***Albert****: So, basically, it's more: it's not just growing as an intellectual person, but also understanding that not only are you more responsible in the sense that, what you do, there's always something else that affects you, or you affect other people, and therefore you can make more educated decisions. That's why I think high school's been very, very important in my life. I don't think…like, I: there needs to be a time, I think, everyone can vouch for me here. But I think every student at one time, at one point, at one time says that: "Oh, I wish high school was over with. I just want it to be done with…And now that I'm nearing the end of that phase, it's sort of like I wish I could have gone back and re-done all of it because...the things I've learned in high school, and the experiences I've had, they're like: they're invaluable. I mean: I wouldn't trade it for anything. (I-2)*

When asked later what he had meant by going back and “re-doing” his classes, Albert said that by doing so he could focus on those life lessons shared by his teachers and stories of the people behind the science that he may not have paid attention to while he was concentrating on marks. In all cases, the inclusion of the students in this research process led to positive views of their roles in the teaching of science, the evidence of which continued in positive reports by the students to me up to two years after they were interviewed.

Another teacher involved in this study was, of course, the researcher. I can honestly say that this experience benefitted and continues to benefit me as a science teacher by having made me more aware of how I teach and that what I do in the classroom can so clearly influence (or be missed) by students in the classroom. I have come to see how science literacy values like those mentioned in this study need to be reinforced, reiterated, and modeled if students are to come to realize the value in them as well.

To the Teaching Profession

Openness to teacher and student participation in this study encourages on-going self-reflection for practicing teachers; the potential for development of classroom scenarios and activities for pre-service teacher education programs; more relevant depth and application of collegial discussions for in-service science teachers; greater teacher confidence in engaging in participation in future research; and greater teacher involvement in curriculum interpretation and development by providing unique perspectives on curriculum decision-making (Wei & Thomas, 2005).

The autonomy – and thus responsibility – of the high school teacher in the choices he or she makes while delivering the content and concepts in programs of study is not an illusion: teachers should continually reflect on their own values and consider how they model or emphasize these values to their students. Teachers should also pause to consider how the students perceive these messages: are they realizing or regurgitating science?

Narrative vignettes and even short comments pulled from observations and interviews in this study could be used to stimulate discussions amongst science teachers (pre- and in-service) to share ideas on how best to address questions and potentially false perceptions of what is of most value when one claims to be scientifically literate. The value domains and categories used to code the transcripts in this study need not be fully applied in the same way, but could be discussed and considered when planning lessons, unit plans, or full-course syllabi. That is not to say that they should be used as a check-list to "hit" every value at least once: It should be clear that, as in the case of this study, delivery of one's own science literacy values must be authentic and ongoing. Teachers must teach from their values or students will see through the pretence. It is also clear that if the teacher comes to understand there are science literacy values he or she may not have considered before, a deeper notion of science literacy can be instilled in his or her teaching. A science lab experience, for example, could be opened up to greater literacy development before (planning and designing the experiment while asking why, if at all, it is necessary to study); during (allowing mistakes and errors to drive discussion and encouraging students to experiment and see for themselves); and after the lab activity itself (evaluating the lab, considering implications of the lab, questioning how it could impact society and may have impacted thinking in the past).

The teachers I spoke with in this study and at subsequent presentations of the findings of this study have been very positive about the value they see in research that uses classroom situations and discussions with students to inform teaching, curriculum development, and teacher education. Some of the teachers I have shared this research with have returned to universities to pursue graduate studies of their own, buoyed by the positive feedback of participants and colleagues. I cannot say that any science curriculum itself will be directly affected by this work, but in discussions with some educators that are involved in curriculum development, revision, and professional development support (in both Alberta Learning and with the College Board's AP® program), I can see that careful consideration of what is happening in the classroom, as described by studies like this one, can have a major impact on how we choose to deliver and assess the content of science without it becoming the only consideration.

Examples of how to apply some of the science literacy values described in this study have been shared by other researchers with commentary and video footage of teaching strategies on Monash University's Science Literacy website (*http://newmedia research.educ.monash.edu.au/drupal/node/1*). As more teachers consider these values, the possible approaches to present and reinforce these values in the classroom could continue to spread amongst educators through media sharing such as this.

Implications of this Study

This study is significant for science educators in several ways. First and foremost, the study demonstrated a way in which science teachers can consider their own teaching practice to determine how their views of science literacy are shared with students in their classrooms. In sharing some examples from this research, teachers will have a model to show how data can support or challenge their own values or provide impetus to communicate values they had not formerly considered. If teachers are using too narrow a view of science literacy, perhaps their students' abilities to appreciate science is also impeded. In such cases, the students (and their teachers) may not be able to reach, or perhaps demonstrate, high levels of science literacy.

Another consideration is training or professional development opportunities for in-service teachers, particularly those moving from course-to-course or stream-to-stream. Do these teachers bring a single preconception of what it means to teach "science" into every class or do they adjust their mental frame for each different group they encounter? As Barton and Darkside (2000) point out, teachers do not need to accept that teaching science is only done in one way: Teachers and students can construct a "local knowledge" (p. 39) of science. Using this same idea of "local knowledge," Berliner (2002) reminds us that teaching involves ubiquitous interactions. In-service teacher training can involve continuous learning in which teachers can become more aware of current research literature involving science literacy, which may make such interactions more visible in their own classrooms. Have recent findings about student/teacher discourse and identity studies informed teaching practice in explicit ways? Are teachers developing their own, custom-tailored science literacy strategies or are they simply reacting to programs of study that provide generic descriptions of what science literacy is? To answer such questions, teachers must begin to reflect on their own values and teaching choices in some substantive way.

A third consideration relates to science teacher hiring practices. If new teachers are not entering science classes, this means that existing teachers, who may have little science training, may be tasked with teaching science courses for which they feel ill-prepared. Will science teachers be more or less likely to "teach" science literacy in courses they are familiar or unfamiliar with and, if so, is this an important consideration when selecting teachers to teach various courses?

Another practical application of this study could be preparation of pre-service science teachers. According to Rascoe and Atwater (2005):

> Most science education programs do an excellent job of teaching pre-service teachers how to reflect. However, this reflection should be directed. Pre-service teachers need the opportunity to put together occurrences of their school day and the roles they may have played in validating their students' self-perceptions of academic ability and in validating themselves as experts in the science content they teach. (p. 909)

How much emphasis should be placed on preparing teachers for planning to teach a wide range of content-heavy curricula? Lee (1995) points out a lack of subject area knowledge may lead to a teacher's reliance on traditional modes of learning, including reliance on textbooks and seatwork, neither of which are conducive to actualizing the full potential of science literacy. Lee also notes that teachers may report low confidence in science content knowledge, but may not seek opportunities to make up for shortcomings, resulting in stalled professional development. In her doctoral thesis, Harcharan Pardhan (2002) describes a move from content knowledge mastery and direct delivery to a consideration of feelings of confidence and competence that teachers develop over time. The difference in these two studies is intent: Lee (1995) points out a problem and Pardhan (2002) engages in action research to address the problem and prevent stagnation. My study, looking at teacher perceptions and manifestation of science literacy in different settings, would be more in line with Lee in that it is designed to learn more about teacher preconceptions. However, my study also lends itself to future research which *could* result in action research like Pardhan's to assist pre-service teachers in planning their future career paths.

Communication of Results

Reporting depends greatly upon the audience that will use this research (Ercikan & Roth, 2006; Erickson, 1986). Studies such as this one include the participants of the study (students and teachers) and other science educators as the main audience with which the results can be shared to stimulate discussion about science literacy. More specifically, these results may inform teachers' considerations of how they present their own science literacy values in their practice. After all: "A model of science teacher knowledge is only useful if it can provide convincing descriptions of real situations, furnish additional insight, and/or provide a way of interpreting the data arising from interviews and conversations with teachers" (Barnett & Hodson, 2001, p. 441).

Hitchcock and Hughes (1995) suggest that a naturalistic approach, such as the one used here, can allow the study of educational activity *in situ*, without constraining, manipulating, or controlling it, *if* the research is seen from a teacher's point of view. Simply put, if teachers do not find research about teaching relevant, they will not adopt it into their practice. This study relates directly to the practice of teaching science, so initial results of this study *were* shared with the teacher and student participants, with the potential for publication in professional journals and presentations at professional conferences of both teachers and education researchers. There also exists the potential to use vignettes formed through data analysis in pre-service and/or in-service teacher training to explore the many facets of science literacy.

In all cases, how science literacy manifests itself in diverse teaching contexts will be the key theme of the message delivered. All participants' names will be kept confidential and pseudonyms will be used if quotations are utilized in presentations.

Potential for Ongoing Research

The qualitative approach taken in this study could be complemented by further studies, incorporating findings to: (a) develop quantitative surveys, (b) inform future interview questions, and (c) develop a science literacy perspective/value-manifestation instrument. Such extension could allow for mixed-methods approaches to the questions raised in this study in hopes of shedding more light on successful teaching techniques and misconceptions arising from the implementation of one's views of science literacy.

The qualitative approach utilized in this study could also be extended to include teachers and students from other schools (including junior high or elementary schools), other jurisdictions, other enrichment programs (such as International Baccalaureate IB®), and/or vocational programs to provide a deeper understanding of contextual affect on science literacy value manifestations. By comparing groups of teachers at different schools, one could also explore how teachers' science values are impacted by overall school cultures. Similar research could be conducted with pre-service teachers to determine if their views and discussion of science literacy change as they enter the profession (similar studies have focused on the use of STS issues in teaching: see Pedretti, 2003), and, perhaps over a longer term, change in any significant way. Longer term ethnographic observation, including collection of artifacts, could be used to extend and/or strengthen the findings of this and other studies.

A potential weakness of the analytical framework was identified when considering the application of this framework to identify the values of teachers in other contexts. As previously noted under "**Limitations**" in Chapter 3, the framework contains different numbers of value categories under the four domains, which must be considered if the framework is shared with participants *prior to* interviews and observations. This disparity could affect transferability of the findings from this study in two ways. First, if either the researcher or participants develop a pre-conception that domains with more value categories should be given more emphasis (simply because they have more value categories) in their interview questions or answers and/or observations or classroom practice, an authentic representation of the participants' own values may be compromised. For example, in the case of applying this framework to observation of a student teacher or beginning teacher as a research participant, the participant could assume that the "Process Values" domain is more important than "Societal" or "Cognitive" value domains simply because the "Process Values" domain has more categories. If the framework is shared in advance, this might set up a false expectation within the participant that this domain *should* be valued more highly during observations, even if that participant would not normally value this category as highly in normal, authentic (that is, "non-observed") practice. As such, the researcher must consider whether the framework is being used to explore (as was the case in this study) or define science literacy values with the participants. If used in the latter case, it would be worth reminding the participants that "more value categories" does not necessarily mean "better" or "more important" domain. Second, category values themselves may need further explanation and/or separation when reporting findings. A good example of this is the “Interdependence” value category under the “Societal Values” domain. Though the overall frequency of codings in this value category was not particularly high in my own study, in other studies it may be necessary to clearly separate the concepts of “applicability to other disciplines”, “harmony with nature”, concerns about “sustainability” of science practices, and “science-technology-society (STS)” to more fully tease out the relative importance of each of these aspects of interdependence in science. As was done in this study with the addition of “Building Student Confidence in Science”, “Facts of Science”, “Developing Models”, and “Other” (see Table 2, page 54), it may be necessary for the researcher to identify new value categories to remain true to the interview responses and observations that occur.

In summary, the researcher must always be cognizant that the analytical framework does affect the way in which data are collected and interpreted. If the framework does not truthfully represent what is important for the participant, then the framework should be modified accordingly.

Conclusion

An excerpt from Alexander Pope’s (1709) *Essay on Criticism* describes my desire in this study to get at “deeper” meanings of science literacy:

> A little learning is a dang'rous thing; Drink deep, or taste not the Pierian spring: There shallow draughts intoxicate the brain, And drinking largely sobers us again... Short views we take, nor see the lengths behind; But more advanc'd, behold with strange surprise new distant scenes of endless science rise!

Science educators should not simply deliver the content in their science classes. Exploring science literacy more deeply can inform teaching practice and provide an opportunity to realize unexplored vistas beyond classrooms and within curricular documents. Exposure to the many science literacy values described in this study could further students' development in all aspects of science literacy, not just content expertise, engaging them to connect to a much wider experience of science practically and intellectually. Teachers may be able to define more clearly the science literacy values they hold, the techniques they have used successfully to engage their students in learning those science values, and to identify the potential in their own teaching to achieve the same high levels (or even greater heights) of science literacy in their students by choosing the different paths illuminated by other science literacy values.

If researchers continue to enter the classroom and witness the *manifestation* of curricular concepts like "science literacy," they will be treated to the marvelous views provided by those tour guides who are "climbing the peaks of pedagogy" every day with their students – the teachers themselves. To truly get at the lived experiences of teachers, researchers must be willing to "drink deeply" and engage in rich, context-laden study of teaching and learning. Hostetler (2005) reassures us that if we stop seeking slogan-worthy answers to educational questions like "what is science literacy?" we will create space to allow remaining questions to stimulate further discussion.

It is interesting that Berliner (2002) states: "Unrestricted questioning is what gives science its energy and vibrancy" (p. 18). This was very much the hope of my own study of science literacy and undertaking this work has inspired me to continue teaching and learning, practicing and researching. It is my hope that this study also has the potential to inspire other science educators by opening a discussion of a key rationale of Alberta Science programs that is too often overlooked in deference to content mastery. Finally, for those who feel that the idea of science literacy is too amorphous, too ambiguous, and too messy, I hope this study opens new views of science literacy for all stakeholders in the education process: to see through science literacy's hazy definitions into its vital and surprisingly clear effects on students in classrooms.

Personal Reflection

The process of engaging in graduate studies made clear the potential disconnect that can arise between research and teaching practice, and that teachers would benefit immensely from time to simply "think" about their own practice. The complexities of engaging in intellectual conversations about science literacy remain daunting, but the effort expended has only fuelled my passion for instigating conversations with my colleagues and the desire to share my own experiences to the research communities of which I have been a part. By doing so, I have been forced to consider and defend, as well as how to improve, my own teaching practice.

This research has also provided me with a better sense of how to answer the questions of parents who need to understand how science students today are asked to think beyond a test, which will be particularly useful when legitimizing the new focus on inquiry in AP® classes. By considering the full spectrum of science literacy presented in the values model, moving students away from content-based science can become more manageable.

More recently, this project has allowed me to share my own passion for the research process by involving more students in secondary level research projects and papers. The opportunity to model the process I have gone through with this project has been invaluable and offered me insights that could only be earned by experiencing the trials and challenges of engaging in graduate level research. The opportunity to share and defend this thesis with the committee members, who are far more experienced in research, enabled me to also consider my own strengths and weaknesses as a researcher, will also prove invaluable when sharing and critiquing research ideas with my students. For these opportunities I am, and will always be, grateful to all those who made this process possible.

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Appendix A: Ethics Approval Letters

UNIVERSITY OF ALBERTA

Gregory Henkelman <ghenkelm@ualberta.ca>

HERO: Ethics Application has been Approved

1 message

hero@ualberta.ca <hero@ualberta.ca>
Reply-To: hero@ualberta.ca
To: ghenkelm@ualberta.ca

Mon, May 31, 2010 at 8:34 PM

University of Alberta

Ethics Application has been Approved

ID:	Pro00013290
Title:	Teacher Enactment of Science Literacy in Different Teaching Contexts
Study Investigator:	Gregory Henkelman
	This is to inform you that the above study has been approved.
Description:	Click on the link(s) above to navigate to the HERO workspace.
	Please do not reply to this message. This is a system-generated email that cannot receive replies.

University of Alberta
Edmonton Alberta
Canada T6G 2E1

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T 780-429-8000
F 780-429-8318
info@epsb.ca
www.epsb.ca

September 14, 2010

Dr. Christina Rinaldi 675.10
Associate Dean, Research and Graduate Studies
845 Education South
University of Alberta
Edmonton, Alberta
T6G 2G5

Dear Dr. Rinaldi:

Re: Henkelman: *Teacher Enactment of Science Literacy in Different Teaching Contexts* (Henkelman)

The aforementioned research request has been approved, subject to the following conditions:

1. Teacher and student participation in the study shall be voluntary;
2. Participants are free to withdraw at any time;
3. Parental permission will be sought for students to participate in the study. **(Absence of written, informed consent must be interpreted as the absence of authorization.)**;
4. Anonymity of the participants and confidentiality of information obtained is assured;
5. Personal information may only be used for the stated purpose for which the information was collected or compiled;
6. The researcher conforms to the requirements of the Freedom of Information and Protection of Privacy Act and Regulation; and
7. The researcher provides a copy of the results to the Associate Dean, Research and Graduate Studies, to be forwarded to Edmonton Public Schools by November 1, 2011.

Gregory Henkelman may now contact the undernoted principal to obtain approval and to make the necessary arrangements for conducting the study. It is the responsibility of the researcher to provide the principal with a copy of the proposal and all related documents, if requested. I wish Mr. Henkelman success in this endeavour and anticipate reception of the results as they become available. For further information, please contact John Macnab at 780-429-8417.

Sincerely,

John Macnab
Research Liaison

JM/mp

Bright futures begin here

Appendix B: Specific Value Categories Based on Frequency in Interviews and Class Observations

HUMAN VALUES (21.2% of ALL codings)	*P30AP Interviews*	*P30AP classes/labs*	*S10 Interviews*	*S10 classes/labs*	*Teacher Interviews*
H1. Curiosity (intellectual curiousity/inquisitiveness)	*32 (24.1%)*	*46 (18.8%)*	*1 (3.6%)*	*49 (18.4%)*	*22 (17.1%)*
H2. Longing to know and understand	*74 (55.6%)*	*66 (26.9%)*	*9 (32.1%)*	*77 (28.8%)*	*37 (28.7%)*
H3. Open mindedness (Openness)	*1 (0.8%)*	*10 (4.1%)*	*3 (10.7%)*	*15 (5.6%)*	*17 (13.2%)*
H4. Integrity (Honesty, Ethical Behaviour)	*1 (0.8%)*	*4 (1.6%)*	*0*	*13 (4.9%)*	*4 (3.1%)*
H5. Creativity (Imagination, Innovation, Inference)	*3 (2.3%)*	*60 (24.5%)*	*0*	*49 (18.4%)*	*13 (10.1%)*
H6. Student Confidence in science (helping build it) (Henkelman)	*22 (16.5%)*	*59 (24.1%)*	*15 (53.6%)*	*64 (24.0%)*	*36 (27.9%)*
TOTALS	***133***	***245***	***28***	***267***	***129***
COGNITIVE VALUES (14.0% of ALL codings)	*P30AP I*	*P30AP*	*S10 I*	*S10*	*Teacher*
C1. Rationality (Logicality)	*2 (9.1%)*	*57 (50.9%)*	*0*	*155 (53.3%)*	*8 (9.2%)*
C2. Search for Evidence (Verifiability, Demand for verification)	*9 (40.9%)*	*38 (33.9%)*	*1 (100%)*	*107 (36.8%)*	*51 (58.6%)*
C3. Skepticism (Questioning)	*11 (50.0%)*	*17 (15.2%)*	*0*	*29 (10.0%)*	*28 (32.2%)*
TOTALS	***22***	***112***	***1***	***291***	***87***
PROCESS VALUES (42.6% of ALL codings)	*P30AP I*	*P30AP*	*S10 I*	*S10*	*Teacher*
P1. Diversity in Scientific Thinking / Different forms of sci. inquiry (Siddique)	*1 (1.7%)*	*19 (2.4%)*	*2 (5.3%)*	*18 (2.8%)*	*7 (2.2%)*
P2. Empiricism	*15 (25.9%)*	*51 (6.5%)*	*3 (7.9%)*	*107 (16.5%)*	*63 (19.6%)*
P3. Parsimony (simplest explanation)	*0*	*3 (0.4%)*	*0*	*33 (5.1%)*	*3 (0.9%)*
P4. Science Community (Co-operation, Collaboration, consensus, communication)	*12 (20.7%)*	*103 (13.2%)*	*8 (21.1%)*	*109 (16.8%)*	*44 (13.7%)*
P5. Accuracy (Authenticity, Precision, Calibration)	*4 (6.9%)*	*97 (12.4%)*	*3 (7.9%)*	*117 (18.1%)*	*19 (5.9%)*
P6. Reliability (Reproducibility)	*1 (1.7%)*	*8 (1.0%)*	*1 (2.6%)*	*42 (6.5%)*	*12 (3.7%)*
P7. Valuing Process (hypotheses, predictions, observations, analysis, interpretation)	*24 (41.4%)*	*386 (49.4%)*	*15 (39.5%)*	*95 (14.7%)*	*94 (29.3%)*
P8. Tentative Nature of Science (Siddique)	*0*	*26 (3.3%)*	*1 (2.6%)*	*29 (4.5%)*	*29 (9.0%)*
P9. Validity (testing what says it is)	*1 (1.7%)*	*6 (0.8%)*	*1 (2.6%)*	*19 (2.9%)*	*24 (7.5%)*
P10. Developing Models (Henkelman)	*0*	*83 (10.6%)*	*4 (10.5%)*	*78 (12.1%)*	*26 (8.1%)*
TOTALS	***58***	***782***	***38***	***647***	***321***
SOCIETAL VALUES (4.9% of ALL codings)	*P30AP I*	*P30AP*	*S10 I*	*S10*	*Teacher*
S1. Objectivity (Neutrality, Reduction of Bias)	*0*	*4 (13.3%)*	*0*	*30 (68.2%)*	*9 (16.1%)*
S2. Interdependence (Applicability, Harmony with nature, Sustainability, STS)	*21 (84.0%)*	*17 (56.7%)*	*24 (96.0%)*	*6 (13.6%)*	*27 (48.2%)*
S3. Meaning making / Historical aspect of science (Siddique)	*4 (16.0%)*	*9 (30.0%)*	*1 (4.0%)*	*8 (18.2%)*	*20 (35.7%)*
TOTALS	***25***	***30***	***25***	***44***	***56***
ADDITIONAL VALUES	*P30AP I*	*P30AP*	*S10 I*	*S10*	*Teacher*
F. Facts of Science (Henkelman) **(15.0% of ALL codings)**	***34***	***192***	***28***	***187***	***110***
O. OTHER (Henkelman) **(1.7% of ALL codings)**	***1***	***9***	***3***	***45***	***4***

Appendix C: Justification of Coding Through Contextualized Examples

Values H=human; C=cognitive; P=process (adapted from Siddique, 2008; Corrigan et al., 2010; and Cooper & Corrigan, 2011)	**Teacher Interviews/Discussion** (Neil) Initial=I-1; Mid-point =I-2; Final=I-3 **Classroom Examples** Physics=P; Science=S; number represents date of class	**Science 10** **Student Interviews** (Jack and Jill) Initial=I-1; Final=I-2	**Physics 30AP** **Student Interviews** (Marie and Albert) Initial=I-1; Final=I-2
H1.Curiosity (intellectual curiousity /inquisitiveness)	"Hey, why did this object just do what it did?" (I-1) "But the idea that: "Let's see what nature does and see if we can figure that out" (I-3) "One kid had asked if he could watch, so he's in there two and I'm down like this (*gets down on his knees*) and I'm gonna light this thing and I'm here, right? And he says to me: 'Is it gonna be loud?' and I say: 'I think so'" (S26) "Now, what will happen to the pattern if I move those sources closer together? Well, let's see: 'hmmm, seems to spread out'" (P20)	"I really like those subjects very much and I like hearing what other people have to say about them." (I-1Jack)	"It's not always about learning explicitly what's the, uh, the curriculum… It's also, like, expanding, just having, like, some random facts or just a good video once and awhile" (I-1Albert) "I really like it when Mr. ***, like, goes and explains things. I think he's really good at it. And I like, like, knowing the history behind some of the science stuff." (I-1 Marie)

H2. Longing to know and understand	"…you experiment to find out if you're right" (I-1) "…human beings got where we were by noticing things, and trying them out again and again, and I think kids are like that" (I-1) "Well, we're split here: interesting. I say it's mercury one oxide and I'm gonna show you why. Okay?" (S16) "No, it's not what we expect, but its close. Again, the real world and this imaginary mathematical physical world, we're trying to see if we can, come close, right?" (P8)	"…it just kinda helps you understand things, in general, I guess: knowing an explanation" (I-1Jill) "Cuz, like, people make theories and it leads to other things, so, if you know it all it's easier to understand." (I-2Jill)	"Well, I think science is a basic understanding, it's like, the groundwork for the universe, really." (I-2 Albert) "Well, because if you don't wonder why things happen, you'll never learn anything more and you'll never get any further with your understanding of anything." (I-2 Marie)
H3. Open mindedness (Openness)	"Because if there's no diversity, all you've got is mediocrity" (I-2) "I'll look at 'em and I'll think: 'That might be a good idea', and I'll try it. And if it works, I'll try it again. If it doesn't work, well, it still might be a good idea for somebody else." (I-2) "Alright, off you go, get your stuff and let's see how it goes" (S30)	"I like hearing what other people have to say about them…I can see a new view on things if they view it differently than I do." (I-1Jack)	"I think it's sort of like, it's just rubbing off. Like, the, the willingness to learn, the willingness to ask questions" (I-2 Albert)

H3. Open mindedness (Openness) ***(continued)***	"You know: so we talk about science being this self-correcting body of knowledge, right? I mean, if you can show something is wrong, then you have to throw it away. It is that, but scientists, especially established scientists, owe everything they know to what they used to know…" (P20)		
H4. Integrity (Honesty, Ethical Behaviour)	"If that theory is right, everything every geologist knows is out the window. You think they wanna switch?" (I-2) "But it would be really neat if something like that happened while you were teaching and you actually went and tore up, you know, your posters in your class. And the kids went: 'Why are you doing that for?' And you said, 'Well, the model is wrong'." (I-2) "Well, you might say yes cuz we got 'em all right, but you might say no because we guessed at two of them and we just happened to get lucky." (S14)	***No examples found in these specific interviews.***	"It's not just growing as an intellectual person, but also understanding that, uh, not only are you more responsible in the sense that, what you do, there's always something else that affects you, or *you* affect other people" (I-2 Albert)

H4. Integrity (Honesty, Ethical Behaviour) ***(continued)***	"And there were people, they ignored his stuff for decades before people finally sort of looked at it and grudgingly admitted that maybe the guy was right…we see all sorts of examples in the history where people don't give up old ideas easily." (P20)		
H5. Creativity (Imagination, Innovation, Inference)	"And they'll be marked on: If they will work, you will get five out of five…Because, there's a lot of different orders that they could do the thing at." (I-2) "But then, okay: "…see this? I want you to take it home and time something fast…So, at this point, having the kids make their own equipment, you know." (I-3) "But there's lots of ways of doing it. We've (*science staff*) been sort of playing around with different ways of doing it and this is what we kind of came up with." (S30)	***No examples found in these specific interviews.***	"Like the people who start the whole thing, that come up with these ingenious experiments. Like, what caused them to think that way and that's how you, that's how I've started to come to answer these questions, not just: "What is the prompt and how quickly can I look this up on Google and answer the question", right? (*I laughs*) That's how I used to do it." (I-2 Albert) "Mm hmm. Ya like, they're like...electrons and stuff that you can't actually see yet." (I-2 Marie)

H5. Creativity (Imagination, Innovation, Inference) ***(continued)***	"But a guy named Thomas Young, a really young guy named Thomas Young, figured out how to do it. And what he did was, he said: 'Well, if light diffracts through an opening, as if the opening produced the wave, well, what if I pass light through two openings at the same time?" (P20)		
H6. Student Confidence (helping build it) (Henkelman)	"So, doing labs is a threat. Not because they might not finish it, but because they're confident that they can get the answers, paper and pencil." (I-1) "One of the symptoms of a weak kid is they do not want to volunteer information, cuz they've probably been wrong so many times they don't want to be wrong again." (I-2) "I want to go over it, there's some things we have to talk about, then what we'll do is I want to give you the background for what we're gonna need for the lab we do tomorrow, okay?" (S26)	"I don't really know cuz I'm really bad at chemistry…" I: So, when you say you're "bad", is it thinking about more like the marks on quizzes or how you do in labs? "Kind of the marks on the quizzes." (I-2Jack) "(So the test doesn't show how much they actually know) 'Ya. Like that, I like, that's why I like our teacher cuz he gives us lots of labs...So we can show other ways to demonstrate our skills'"(I-2 Jill)	"Um, I'd say it's having an understanding of, like, basic science concepts and stuff, and being able to apply that to other things, as well as learning, being willing to learn more and question things." (I-2 Marie) "But sometimes the teacher will have to, kind of, like, pull it out of you, kind of, tease it out of you. But, I mean, alot of times, it's just the students coming up with questions on their own." (I-2 Albert)

H6. Student Confidence (helping build it) (Henkelman) ***(continued)***	"Now, are there any questions about the lab that we're gonna hand into me next class? So hopefully you had a chance to do that, and figure out what it's about, okay? Piece of cake lab, eh? (*some students say: ya*). Ya? Good." (P20)		
C1. Rationality (Logicality)	"Science says: 'I think this is what's going on, I'll run an experiment to see'. What math is: 'I will accept these axioms as being true and then I'm just gonna logically see where that takes me'" (I-3). "So, like that's what you hope, is that: Okay, we've built in a healthy skepticism, you don't just accept what somebody says, you look at the data." (I-3) "Now, a flow chart: you basically are going to say: 'Do this first, and if it does this, then you're gonna go this way and if it does this, then you're gonna go this way, and you're gonna test something else." (S26). "Now, as I move this thing closer and closer, it repels stronger and stronger. And it gets harder and harder and harder to move it, right?" (P4)	***No examples found in these specific interviews.***	"In AP, it was a more, there was more development on how to get to the process, like, what the processes are, leading up to an answer. " (I-2 Albert) "What they were looking for, I think that's important to, kind of, building that process of how to think and building those bridges to get to where you want." (I-2 Albert)

C2. Search for Evidence (Verifiability, Demand for verification)	"…you think about what's going on, and why, and you experiment to find out if you're right" (I-1) "…what needs to be presented as evidence, like a lot of them didn't know that. They knew the answer to the question…But they had no concept about, how, you know, what you would have to do." (I-2) "Yes it is, now let's go back one step and figure out why" (S16) "And, where we're headed with this is, we're gonna take light and we're gonna see if we can produce these interference patterns, and we're gonna develop an equation that tells us where we might expect those nodes, and anti-nodes to occur. Okay?" (P20)	"Uh, it was, like, about this, like, murder mystery. And, like, there was an unknown substance used, so we had to, like, figure out what chemicals were used, just so we could figure that out. That was, like, pretty important, I found." (I-2 Jack)	" But if you question it, and experiment on it, you can figure out why it is the way it is." (I-2 Marie) "And just trying to figure it out for yourself what you want to know and why things work." (I-2 Albert)
C3. Skepticism (Questioning)	"…most of the kids, if that's all they ever get and they develop a little bit of skepticism about, well, "You say this, but I'm gonna try it and see", then I think, you know, that's, that's great for most of us" (I-1)	***No examples found in these specific interviews.***	"But, as long as you can continue learning and questioning things, and not just take it for what it is, that's probably pretty important." (I-2 Marie)

C3. Skepticism (Questioning) ***(continued)***	"So, like that's what you hope, is that: Okay, we've built in a healthy skepticism, you don't just accept what somebody says, you look at the data." (I-3) "Did you know there's as much sodium in a glass of milk as there is in a sport drink? Check the label sometime: it's true." (S16) "Maybe the results aren't exactly what the theory says, but we come close: who knows? We had one one time where we had a rip in it, like this, so I had the students use it anyway to see if that rip on the surface would have an effect on the electric field" (P8)		"I think a big part of it is this understanding why and asking and confonting and, uh, it's sort of like this, uh, renaissance idea of challenging what's already there? " (I-2 Albert)
P1. Diversity in Scientific Thinking / Different forms of scientific inquiry (Siddique)	"Because if there's no diversity, all you've got is mediocrity. You know, how, you know: The only way you can get everybody on the same page is to get everybody at the average value. And, and that's just not interesting." (I-2) "…the more the discussion leads to another possible way you can get kids to actually do something, I think that works better." (I-3)	"So we can show other ways to demonstrate our skills" (I-2 Jill) "Cuz, like, people make theories and it leads to other things, so, if you know it all it's easier to understand." (I-2 Jill)	"I think going through things in different ways. Like, showing, telling them it, and then, like, doing a lab to get them to understand it, and then maybe showing a video on it, or something….So they have more than one way to look at it…. And see different point of views on the same thing." (I-2 Marie)

P1. Diversity in Scientific Thinking / Different forms of scientific inquiry (Siddique) ***(continued)***	"Now, chemistry is, to my mind, the best subject for always drawing a distinction between knowing stuff from a theory and knowing stuff from experiment. It's just a beautiful science for making that distinction." (S14) "So I truly believe that what Einstein did isn't just a mathematical model of why gravity acts the way it is, I believe that he actually discovered an actual distortion of space itself. Okay, now I'm not: there are people who would disagree with me, but that's their problem, not mine." (P20)		
P2. Empiricism	"Science *is empirical first*, and theoretical second, and most people don't think that" (I-1) "…they never actually got to actually see it, you know, happen in front of them" (I-2) "Knowledge we know from experiment is called 'empirical knowledge'. Now I don't know if you guys will, you probably won't get tested on this word, but empirical knowledge comes from experiments…" (S14)	"And then I think I'd move onto a lab to demonstrate it and show how they'd use it." (I-2 Jill) "…there was an unknown substance used, so we had to, like, figure out what chemicals were used, just so we could figure that out." (I-2 Jack)	"All the sciences and all the subjects kind of talk about a cause and effect realtionship." "And just trying to figure it out for yourself what you want to know and why things work." (I-2 Albert) "But if you question it, and experiment on it, you can figure out why it is the way it is." (I-2 Marie)

P2. Empiricism ***(continued)***	"So what we want to do, I'm gonna…we're gonna go into the lab and you guys are going to look at some real circuits, and you're going to try to answer some questions about those real circuits, okay?" (P12)		
P3. Parsimony (simplest explanation)	"And we'll use the easiest model that we can possibly use to answer the questions that we made." (I-2) "So, expansion and contraction still work and, uh, you know. All the things that the simple theory was good for still work." (I-3) "What makes more sense? Gain 5 to fill, lose 3 to empty?" (Class almost in unison says lose 3). "ya, and it's almost always the simpler one, so it's lose 3." (S14) "So let's see. So our current is coming. A positive, through here to through here, to negative, then through here and through here and back. Now, we're not seeing anything happening, right? (*Student: 'Ya'*). So I'm gonna suggest that you guys get a different, uh, battery." (P12)	***No examples found in these specific interviews.***	***No examples found in these specific interviews.***

P4. Science Community (Co-operation, Collaboration, consensus, communication)	"We're gonna do the lab, and I'm gonna ask you some penetrating questions, and you're gonna have to explain what went on. And if you can do that, then you can answer any question that they can throw at you on that test". (I-1) "Because, you've got people saying everything, so, if you can't directly do the experiment yourself, then if you understand that that's how science works, then that might help you know who to, you know: Like, who is a good source for this versus who isn't a good source for this?" (I-3) "And again, the 'International Union of Pure and Applied Chemistry' … they set the rules for everybody. So if you picked up a Polish textbook, and it's all in Polish, which uses a cryllic alphabet, it's not even our alphabet, you would be able to read the chemistry symbols perfectly because they're exactly the same for everybody in the world. Because everybody chooses to follow those rules." (S14)	"My brother, he had to do a science project and, they had them mix some things together and my parents weren't home …because of what I learned in my Grade 7 classes, I was able to help him somewhat." (I-1 Jack) "And then it's, when you're talking to someone, in like Germany, then, then you would have less trouble explaining, I think? Because you wouldn't have to go to every word and tell him what it is in their language." (I-2 Jill)	"It helps you understand things. I like, like, cuz at conversation at supper and stuff, something will come up and I'll be, like, "Well, blah blah blah blah". Ya. It makes you sound smart." (I-1 Marie) "I think it's a coalition between the teacher and the students that are required to work together to provide that kind of atmosphere." (I-2 Albert)

P4. Science Community (Co-operation, Collaboration, consensus, communication) ***(continued)***	"And he wrote it up and he ticked off a lot of scientists, because: he was a young guy, he was just starting out and who is he to challenge the great Isaac Newton? And there were people, they ignored his stuff for decades before people finally sort of looked at it and grudgingly admitted that maybe the guy was right." (P20)		
P5. Accuracy (Authenticity, Precision, Calibration)	"I'm going to make them, uh, write another quiz and another quiz until at least they've got at least some pretty good, you know, skills that way. But there's no shortcut to being able to write a chemical formula" (I-2) "It's, it's notoriously difficult to get. So what we did is we turned it around this year and said: "Well here's three or four ways you can set it up. Is this equipment good enough to show the model?" (I-3) "Now, again, you didn't have to do that in Junior High when you were writing things, but I'm going to insist, everytime you write a chemical formula, we're gonna put solid, liquid, gas behind it."(S16)	"Like all the important stuff…he really teaches us, he gets down to details… So I guess he'd want us to remember the details of it and he goes over it alot, so, know the whole part. Like, not just parts of the subject or anything." (I-2 Jill) "If you don't understand the formulas, you don't understand how to do the question, then you lose marks." (I-2 Jack)	"We also did the hydrogen spectrum so you could see, like, where the spectral lines are, and stuff, and the diffraction of the light and it actually: I got, like, four per cent error, so that's pretty good." (I-2 Marie) "Well especially with, like, labs, cuz some teachers don't care about all the particulars as much as he, he does care about those, so… labelling all the graphs right, and stuff, so." (I-2 Marie)

P5. Accuracy (Authenticity, Precision, Calibration) ***(continued)***	"Now, which is the safer equation to use? (*Student: 'The sine?'*). Ya, cuz this only depends on one approximation, this depends on a second approximation." (P20) "Now again, I should do this an infinite number of times here." (P4)		
P6. Reliability (Reproducibility)	"So, it doesn't matter anyway, but just because it's gonna make it easier for me to mark the lab itself, um, I'm gonna give them the flow chart, my flow chart: that's the one they're going to be asked to follow when they go in there." (I-2) "It's, it's a little artificial, but I think, um, the activities that you write in your (text) book absolutely have to be, uh, good, they have to work" (I-3) "Well, if they're ionic, they should behave like this, if they're molecular, they should behave like that, if they're acids, they should behave like this, and if they're bases, they should behave like that." (S26)	"So if someone else were to come and do their work…they'd be able to follow it as well." (I-2 Jill)	"We tested the photoelectric effect, which...Our equipment isn't super great, so we got a pretty big percent error. But, you...you could see how it *could* work." (I-2 Marie)

P6. Reliability (Reproducibility) ***(continued)***	"Now, if it's true that the angle is very small, both equations will give you the exact same answer, probably up to 5 or 6 significant digits." (P20)		
P7. Valuing Process (hypotheses, predictions, observations, analysis and interpretation, conclusion)	"So you might look at the kid and say: "Could you test that? How?"" (I-1) "…there's an issue between what is an observation in a lab versus what is an inference, or a, a thing based on that. Uh, what needs to be presented as evidence, like a lot of them didn't know that. They knew the answer to the question". (I-2) "So everybody, I want you to take 5 minutes, you're going to say 'we got this many right, we think this was a 'blank' way of doing this, and this is what we think was good or bad about it' or something like that, okay? I want your judgment. Okay?" (S14) "Okay, so, next class, you won't be listening to me that much. You guys will be seeing, hopefully if these ideas actually, if we can actually detect with these ideas" (P4)	"We do labs and we learn procedures before and then we actually get to put them in place during the lab so it really helps us learn." (I-2 Jill) "…so we had to, like, figure out what chemicals were used, just so we could figure that out. That was, like, pretty important, I found….in terms of the practical use." (I-2 Jack)	"I think it's more of a, like the science classes take more of an aspect on, like, the theory. I: Mm hmm. TN: Like, building your, um, education upon the theory, and then applying it to things"(I-1 Albert) "I don't know: if they just stand back there and just let other people kinda do the lab for them, that's not really helping them. But if they actually get involved and do the lab themselves, that's better." (I-2 Marie)

P8. Tentative Nature of Science (Siddique)	"…you always hear the media going: "Well, I want scientific proof", and you know, there's no such thing." (I-1) "And everything in science is supposed to be a working model for now." (I-2) "For example, you know that an acid is a substance that turns blue litmus red. Chemists still don't know why. Chemists do not actually know, for sure, what acids and bases are. They don't have a theory that works for all of them." (S14) "Depending on your initial…and what you have is: if the initial condition changes by the tiniest amount, it changes everything, and that's what chaos theory is all about." (P4)	"Cuz, like, people make theories and it leads to other things, so, if you know it all it's easier to understand." (I-2 Jill)	***No examples found in these specific interviews.***
P9. Validity (testing what says it is)	"Well, we're assuming that they're point sph- point charges, but as they get closer and closer together, that assumption might become less and less valid" (I-1) "'Well, we still don't think it's a great method because there were so many different shades of blue'".(I-2)	" Well, labs always work. And, um, trying to relate what we're learning to something real life makes them grasp, well, it makes me grasp the concept better." (I-1 Jill)	"Which, I think a big part of labs is questioning it, cuz if you just accept the theory, that's just: you don't really understand why it is that way." (I-2 Marie)

P9. Validity (testing what says it is) ***(continued)***	"Ya, you can't use city water, cuz city water contains ions that will contaminate the whole thing that we're trying to do" (S30) "No, it's not what we expect, but its close. Again, the real world and this imaginary mathematical physical world, we're trying to see if we can, come close, right?" (P8)		
P10. Developing Models (Henkelman)	"In junior high, you needed to know it, you needed a simpler model, for what you needed to do", uh, "We need a little bit different model for what we wanna do now" and it's all about models" (I-1) "Well, that model you're using, what assumptions are, is that model based on?" (I-1) "So it's got 13 protons in the nucleus, it's got 2 electrons at the first energy level, it's got 8 electrons at the second level, and it's got 3 electrons at the top level. (draws onto chart on whiteboard as he says them). Okay? It looks like that." (S14)	"In my computer class, like, uh, something we did do to science was, we had to, for a couple presentations, when we had a, like, chemist come to our school, we had to, like, put together these models for him and stuff like that, for like, these digital models…" (I-1 Jack) "If it's all really well explained, I think it would help everyone learn. I: Okay. And what would your explanations involve? Diagrams, and details, and examples." (I-1 Jill)	***No examples found in these specific interviews.***

P10. Developing Models (Henkelman) ***(continued)***	"And, where we're headed with this is, we're gonna take light and we're gonna see if we can produce these interference patterns, and we're gonna develop an equation that tells us where we might expect those nodes, and anti-nodes to occur. Okay?" (P20)		
S1. Objectivity (Neutrality, Reduction of Bias)	"…you always hear the media going: "Well, I want scientific proof", and you know, there's no such thing" (I-1) "In religion, you accept certain truths on faith, and your truth comes through your faith". I said: "That's not scientific". (I-3) "You would be able to read the chemistry symbols perfectly because they're exactly the same for everybody in the world. Because everybody chooses to follow those rules." (S14) "Find a place close to zero and mark it and once you get the pattern, and we'll see what the pattern shows" (P8)	***No examples found in these specific interviews.***	***No examples found in these specific interviews.***

S2. Interdependence (Applicability, Harmony with nature, Sustainability)	"The focus now is, well, we've got a body of knowledge we have to know, but then there's also the whole citizenship side of things, and all these other kinds of things..." (I-2) "I don't know whether there are some societal things that you could measure, you know. Cuz if we're producing scientific literate people in a democracy, we ought to see that reflected in some voting". (I-3) "Your body uses sodium ions to help nerve impulses move back and forth sort of thing, so the ion form is totally different than the atom form." (S16) "And that's sort of extended the magnifying power of our biggest telescopes, by actually using gravity to act as a virtual lens out there to help us do it." (P4)	"Just, like, the learning of students and what it brings to us, and how it helps us…And the use, how useful science is." (I-1 Jill) "…because of what I learned in my Grade 7 classes, I was able to help him somewhat" (I-1 Jack)	"I think so, ya. I think it will help you understand the world better, and what's going on." (I-1 Marie) "It's not just growing as an intellectual person, but also understanding that, uh, not only are you more responsible in the sense that, what you do, there's always something else that affects you, or *you* affect other people, and therefore you can make more educated decisions" (I-2 Albert)
S3. Meaning making / Historical aspect of science	"…you know you're still teaching the physics, but you're talking about who did what, and this kind of thing, that, uh, that helps them learn." (I-2)	"Cuz, like, people make theories and it leads to other things, so, if you know it all it's easier to understand." (I-2 Jill)	"And I like, like, knowing the history behind some of the science stuff." (I-1 Marie) "Like the people, like the Millikin oil experiment, for example…the people who start the whole thing, that come up with these ingenious experiments." (I-2 Albert)

S3. Meaning making / Historical aspect of science ***(continued)***	"And you would think that astronomy would be Nature of Science. You know, like, Galileo did this and this and this and this, right? It wasn't, it was science and technology". (I-3) "Actually, the Bunsen burner was invented by Robert Bunsen, who was working with Gustav Kirchov, and they're the guys who discovered spectroscopy, the idea that different light produces different things. The Bunsen burner was *invented* to do flame tests…it was the chemists who were the first people to use it."(S30) "And it wasn't until the late 1800's that someone was able to do a measurement of, not the speed of light cuz that took until 1921, but to, uh, they could show that light slows down in water." (P20)		
Facts of Science (Henkelman)	"…a body of knowledge that we've learned as a result of the scientific method" (I-1)	"I'd do tests, just to see if they, they've memorized it, kind of thing, and got it in their brain. And then if they didn't do too good on the test, I'd go back to explanations and do more to get it." (I-2 Jill)	"It doesn't matter if you remember exactly how to calculate the momentum of a proton in an electric field." (I-2 Marie)

Facts of Science (Henkelman) ***(continued)***	"***, he would say: he didn't like doing labs. He's a: 'you're wasting my time. You know what the answer is, so why do I have to do this lab to pretend to find out what it is when we know what it is: just tell me what it is!'" (I-1) "…we still have to go through the, the grunt work, I guess it is, of getting them to know the stuff they have to know." (I-2) "Metals are all the elements that lose electrons to form positive ions. Non-metals are the elements that gain electrons to form negative ions…Now, define: metal, non-metal." (S14) "…a particle will actually refract and follow Snell's law, except it will bend toward the normal when it speeds up and then away from the normal when it slows down." (P20)	"Because, basically my whole class learned pretty quick that if you don't know some formulas, you're not gonna get a good chunk of the final quiz." (I-2 Jack)	"Regular classes, they don't emphasize at all, um, from what I've experienced anyway. It's just been clear-cut details, what you need to know and nothing in between. It's sort of just...giving it to you and just, just accept it, kind of. Um, it seems almost, like, religious in a sense that it's like, they just, like, preach out what you need to know" (I-2 Albert)
Other (Henkelman)	"…because I told her she didn't have to believe it (evolution), then she's happy to answer my questions for me, which is kind of interesting." (I-1)	"Well, you can use it, like, personal safety when you're dealing with things. Um, in science you learn about chemicals and what they do." (I-1 Jill)	"Uh, I'm thinking of going into medicine. I don't really know what I want to do, specifically, I'm thinking of kind of like, a dentist. But, depending on how that goes, I don't know if I'll like it or not." (I-1 Albert)

Other (Henkelman) ***(continued)***	"…they come to us with 'anti-science backgrounds', they come to us with 'science is too hard backgrounds'" (I-2) "Plus they get to light fires...They get to light Bunsen burners, they're gonna love it." (I-2) "It's the fluoride ions that we put into toothpaste, cuz the fluoride ion, then, bonds to the tooth enamel and makes it harder for the bacteria to give us tooth decay and that kind of stuff, okay?" (S14) "By the way, this will be the only time probably that we do a lab that we plug into 120 volts that can kill you. So, one thing you would not want to do once we start this would be to open one of these and stick your fingers in there."(P12)	"I wanna be a dentist, when I grow up, so, uh, if that, if I go with that, I'll be doing lots of science." (I-1Jill)	"I'm thinking of either going into computing science or engineering. I: Okay. And what draws you to those two fields? SM: Math and Science. That's what I like." (I-1Marie)

Appendix D: Examples of Values Coded with Explanations

Values H=human; C=cognitive; P=process	**Value Coding Example**	**Explanation of Context Informing the Coding**
H1.Curiosity (intellectual curiousity /inquisitiveness)	"Now, what will happen to the pattern if I move those sources closer together? (*pause*) Well, let's see: 'hmmm, seems to spread out'" (Physics 30AP, Sept. 20, 2011)	In this example, Neil is demonstrating wave interference patterns by showing video clips. He sets up each scenario then asks the question to stimulate interest and then pauses to let the students contemplate a possible answer and create a bit of suspense. Neil then shows the clip, and models being a student himself to increase buy-in: like he is also discovering the answer with them. The students are engaged in the exercise because Neil is using these clips to build towards a mathematical explanation later in the class.
H2. Longing to know and understand	"Well, we're split here: interesting. I say it's mercury one oxide and I'm gonna show you why. Okay?" (Science 10, Sept. 16, 2011)	In this case, Neil has presented a more complex chemical nomenclature example, where students have to choose between one of two ionic states for mercury. After allowing students time to determine an answer themselves, he asks which state is the correct one, surveying the class. As the class result is split, he honours the difference and then, instead of just saying one answer is right and moving on, he uses this as an opportunity to model a thinking process that allows all students to develop understanding.
H3. Open mindedness (Openness)	"You know: so we talk about science being this self-correcting body of knowledge, right? I mean, if you can show something is wrong, then you have to throw it away. It is that, but scientists, especially established scientists, owe everything they know to what they used to know…" (Physics 30AP, Sept. 20, 2011)	Here, Neil is discussing how the theory they are studying has displaced a previous theory. As a result, he uses this as an opportunity to show how scientists must be open to alternative explanations, or science could stagnate by refusing to change. By doing this, Neil also shows a human side of science by later discussing scientists who find it difficult to give up their own assumptions. By showing these scientists as reluctant, but eventually supporting the new theory, Neil shows a value of openness.

Values H=human; C=cognitive; P=process	**Value Coding Example**	**Explanation of Context Informing the Coding**
H4. Integrity (Honesty, Ethical Behaviour)	"Well, you might say yes cuz we got 'em all right, but you might say no because we guessed at two of them and we just happened to get lucky." (Science 10, Sept. 14, 2011)	Neil takes up a lab experiment from the previous period with his students. Instead of simply having the students mark their answers as right or wrong, Neil asks the students to evaluate the lab itself: did the procedure itself provide a good method for identifying each unknown, or did the students simply "guess" the answer and get it right? This moves students away from ONLY valuing the "right" answer and gets students to develop self-reflective honesty in terms of whether they were able to arrive at the correct answer via work or luck. By "calling out" students who simply guessed, Neil shows the value of "coming clean" about how answers are arrived at.
H5. Creativity (Imagination, Innovation, Inference)	"But a guy named Thomas Young, a really young guy named Thomas Young, figured out how to do it. And what he did was, he said: 'Well, if light diffracts through an opening, as if the opening produced the wave, well, what if I pass light through two openings at the same time?" (Physics 30AP, Sept. 20, 2011)	In this example, Neil is describing how Thomas Young solved a problem that had plagued physicists as they struggled to resolve the wave/particle theory of light. After discussing the difficulty Isaac Newton had in getting two light sources in phase, Neil describes how Young used a very simple, innovative technique to do so using the understanding that two waves passing through an opening will diffract as if they were originating at the opening. This inference, and Young's creativity, provided an innovative solution to the problem.
H6. Student Confidence (helping build it) (Henkelman)	"I want to go over it, there's some things we have to talk about, then what we'll do is I want to give you the background for what we're gonna need for the lab we do tomorrow, okay?" (Science 10, Sept. 26, 2011)	In this example, Neil is taking up another laboratory experiment with his students. In this case, however, Neil is not simply finishing up a discussion about the experience: he is using the experience to help build the students' skills and confidence with the procedure to carry out the next lab the following period. In this way, Neil demonstrates a concern for students in developing the skills they need to be successful.

Values H=human; C=cognitive; P=process	**Value Coding Example**	**Explanation of Context Informing the Coding**
C1. Rationality (Logicality)	"Now, a flow chart: you basically are going to say: 'Do this first, and if it does this, then you're gonna go this way and if it does this, then you're gonna go this way, and you're gonna test something else." (Science 10, Sept. 26, 2011).	In this case, Neil has asked the students to develop a flow chart to use in an experiment the next day to separate a number of compounds from each other and identify what they are. The flow chart is a very logical progression of tests of the substances to reach clear conclusions for each and every substance. By having the students develop the flow chart themselves, Neil demonstrates to students the importance of being able to think and plan logically.
C2. Search for Evidence (Verifiability, Demand for verification)	"And, where we're headed with this is, we're gonna take light and we're gonna see if we can produce these interference patterns, and we're gonna develop an equation that tells us where we might expect those nodes, and anti-nodes to occur. Okay?" (Physics 30AP, Sept. 20, 2011)	Rather than simply teach an equation to his students, Neil models the value of seeing patterns that *will be* described by the equation first. In this way, the equation itself will verify what students have actually seen. This also suggests primacy of the experiment and evidence itself (in this case) when developing models that explain natural phenomena.
C3. Skepticism (Questioning)	"Did you know there's as much sodium in a glass of milk as there is in a sport drink? Check the label sometime: it's true." (Science 10, Sept. 16, 2011)	A very simple remark when discussing various elements in an introductory chemistry lesson, but one that suggests to students that they should not simply accept what they are told and that they can seek evidence on their own.
P1. Diversity in Scientific Thinking / Different forms of scientific inquiry (Siddique)	"Now, chemistry is, to my mind, the best subject for always drawing a distinction between knowing stuff from a theory and knowing stuff from experiment. It's just a beautiful science for making that distinction." (Science 10, Sept. 14, 2011)	Neil introduces a very important aspect of scientific inquiry to students by clarifying the distinction between empirical and theoretical investigations. Throughout this class, Neil had the students provide both empirical and theoretical properties of substances (e.g. Empirical: acids turn blue litmus red; Theoretical: acids donate protons) to show there are a number of ways to identify a substance. By valuing both approaches, Neil shows acceptance of multiple forms of inquiry.

Values H=human; C=cognitive; P=process	**Value Coding Example**	**Explanation of Context Informing the Coding**
P2. Empiricism	"Knowledge we know from experiment is called 'empirical knowledge'. Now I don't know if you guys will, you probably won't get tested on this word, but empirical knowledge comes from experiments…" (Science 10, Sept. 14, 2011)	Not only does Neil consistently request students to engage in empirical analysis, he clearly defines it in this case. Neil values students doing their own work and making their own observations, rather than simply interpreting the data generated by others. By having students do their own work, Neil demonstrates a strong conviction towards sharing this value.
P3. Parsimony (simplest explanation)	"So let's see. So our current is coming. A positive, through here to through here, to negative, then through here and through here and back. Now, we're not seeing anything happening, right? (*Student: 'Ya'*). So I'm gonna suggest that you guys get a different, uh, battery." (Physics 30AP, Dec. 12, 2011)	While Neil could simply have told the students to get a new battery in this experiment in which students are building circuits, he takes them through the circuit to consider what may be wrong, and prompts them to verify his statements. Neil then tells them to consider the simplest solution: the problem may be the battery, rather than their circuit (which, as it turns out, was the correct solution).
P4. Science Community (Co-operation, Collaboration, consensus, communication)	"And again, the 'International Union of Pure and Applied Chemistry', which is what that IUPAC thing stands for at the top of your thing, they set the rules for everybody. So if you picked up a Polish textbook, and it's all in Polish, which uses a cryllic alphabet, it's not even our alphabet, you would be able to read the chemistry symbols perfectly because they're exactly the same for everybody in the world. Because everybody chooses to follow those rules." (Science 10, Sept. 14, 2011)	Neil provides detailed context to the rules the students are learning as they tackle the nomenclature of chemistry. What makes this especially interesting is the way in which Neil shows the students that what they are learning is internationally relevant, making them part of the community they are studying. Both students (Jack and Jill) in their second interviews reflect that the language of science is important, which attests to the value they have internalized with respect to getting nomenclature correct.

Values H=human; C=cognitive; P=process	**Value Coding Example**	**Explanation of Context Informing the Coding**
P6. Reliability (Reproducibility)	"Well, if they're ionic, they should behave like this, if they're molecular, they should behave like that, if they're acids, they should behave like this, and if they're bases, they should behave like that." (Science 10, Sept. 26, 2011)	When discussing the behaviours of various substances, Neil discusses how, empirically, one should be able to identify these substances time after time. The assumption here is that, no matter who is viewing the behaviour of the substances, they will do the same thing.
P7. Valuing Process (hypotheses, predictions, observations, analysis and interpretation, conclusion)	"Okay, so, next class, you won't be listening to me that much. You guys will be seeing, hopefully if these ideas actually, if we can actually detect with these ideas" (Physics 30AP, Nov. 4, 2011)	Neil clearly indicates to students as he begins his description of the next class that they will be responsible for carrying out their own investigations in the lab. Neil also hints at the ability to predict what might happen, that there are ways to test these predictions and the overall theory, and that observations will be necessary in the process to draw conclusions about whether these ideas do apply.
P8. Tentative Nature of Science (Siddique)	"For example, you know that an acid is a substance that turns blue litmus red. Chemists still don't know why. Chemists do not actually know, for sure, what acids and bases are. They don't have a theory that works for all of them." (Science 10, Sept. 14, 2011)	As the chemistry component of Science 10 requires students to memorize facts and patterns, opportunities to demonstrate that science is not "complete" may seem lacking to students. In this example, Neil takes a well-known empirical "fact" about acids and bases and shows that the reason "why" we see the effects of these chemicals is still not understood. Though done quickly, Neil again demonstrates that facts are themselves indicative of a deeper (and often incomplete) understanding of nature.
P9. Validity (testing what says it is)	"No, it's not what we expect, but its close. Again, the real world and this imaginary mathematical physical world, we're trying to see if we can, come close, right?" (Physics 30AP, Nov. 8, 2011)	In this example, Neil addresses the concern of an investigation that provides results that are not "perfect". Rather than dismiss the results altogether, Neil reminds students that physical models are not reality, but also stimulates them to question whether it is "close enough" to be deemed of value.

Values H=human; C=cognitive; P=process	**Value Coding Example**	**Explanation of Context Informing the Coding**
S1. Objectivity (Neutrality, Reduction of Bias)	"You would be able to read the chemistry symbols perfectly because they're exactly the same for everybody in the world. Because everybody chooses to follow those rules." (Science 10, Sept. 14, 2011)	As discussed previously, Neil's emphasis on the universality of chemical nomenclature was central to Science 10. By saying that "everybody" follows these rules, Neil suggests objectivity and neutrality in that one's own personal bias or nationality will not change the rules.
S2. Interdependence (Applicability, Harmony with nature, Sustainability)	"And that's sort of extended the magnifying power of our biggest telescopes, by actually using gravity to act as a virtual lens out there to help us do it." (Physics 30AP, Nov. 4, 2011)	While discussing how gravitational forces can affect the path of light, Neil provides a practical application of the theory. While not focused on harmony and sustainability, this type of statement does suggest that what is learned in class is applicable outside of it. By using a space technology example (space telescopes), Neil is also demonstrates a connection between physics and engineering problems. It also shows that nature itself, through its physical laws such as gravity, can be used to help satisfy human curiousity.
S3. Meaning making / Historical aspect of science	"Actually, the Bunsen burner was invented by Robert Bunsen, who was working with Gustav Kirchov, and they're the guys who discovered spectroscopy, the idea that different light produces different things. The Bunsen burner was *invented* to do flame tests, because it was the chemists who were the first people to use it."(Science 10, Sept. 30, 2011)	Clearly, Neil enjoys using short historical stories to contextualize the skills, techniques, and technology the students are using in his class. What makes this example even more well timed is that the students in this case were actually using the Bunsen burners to do flame tests. As such, Neil places his students within the larger science community to have used this technology in the same way, connecting past and present.
Facts of Science (Henkelman)	"…a particle will actually refract and follow Snell's law, except it will bend toward the normal when it speeds up and then away from the normal when it slows down." (Physics 30AP, Sept. 20, 2011)	Both Science 10 and Physics 30AP classes showed several examples of science "facts" that students were being asked to remember and repeat, but this statement also shows a "fact" can also be defined as a consistent application or result of a law: in this case Snell's law. Neil is asking the students to accept this fact in order to discuss whether light acts more as a particle or as a wave. By accepting the "fact" of Snell's law, the behaviour of light will provide insight into its character.

Values H=human; C=cognitive; P=process	**Value Coding Example**	**Explanation of Context Informing the Coding**
Other (Henkelman)	"By the way, this will be the only time probably that we do a lab that we plug into 120 volts that can kill you. So, one thing you would not want to do once we start this would be to open one of these and stick your fingers in there."(Physics 30AP, Dec. 12, 2011)	One of the most common type of "Other" mentions in both Science 10 and Physics 30AP classes were related to the value of performing science safely (or using science knowledge to do something more safely), both inside and outside of the lab. Though it could be argued this is a process skill, in each case of "warnings" like this one given by Neil in a Physics 30AP circuits lab, it was clear that he was separating these warnings from the description of the procedure the students would follow, likely to more strongly emphasize the need for caution.