TEACHING INQUIRY IN SECONDARY SCHOOL SCIENCE:
BELIEFS AND PRACTICE, CHALLENGES AND
PROGRAM SUPPORT

by

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Abstract

In spite of a multi-decade mandate to enact inquiry in science, research reports that a large gap continues to exist in Ontario between the vision of science education presented in curriculum documents and what is enacted in the classroom. A three-staged, mixed methods design was chosen to examine teachers’ beliefs and practices that contribute to an understanding of this longstanding gap in teaching practice related to inquiry.

The participants in this study were secondary school science teachers currently employed by one medium-sized, urban & rural district public school board. Quantitative data was first collected through a self-reporting survey designed to explore teachers’ beliefs related to teaching and learning in inquiry. Completed questionnaires were submitted by 80% (n = 83) of the population of science teachers. Qualitative data, collected through semi-structured interviews (n = 17), were used to confirm and expand the quantitative findings.

Quantitative analysis resulted in the development of an empirical framework to illustrate the dimensionality of teachers’ beliefs and practices related to inquiry. Four types of science teachers were identified during qualitative analysis, each associated with a preferred type of inquiry and each identifiable by a cluster of beliefs. A stance was determined for each of these types of teachers representing their generalized view of teaching and learning related to inquiry including: utilitarian science, content-based science, authentic contextual science, and citizenship science. Additionally,
each group of teachers could be associated with one of the four quadrants in my framework. Lastly, a beliefs profile was produced to represent each quadrant in this framework based on integration of the quantitative and qualitative findings.

Challenges to enactment and types of program support to foster enactment of open-ended inquiry were identified by science teachers associated with each stance. A few of these challenges and types of program support represent newer areas for research that can inform educational leaders and teacher-educators and support decision-making so as to meet the diverse needs of both pre-service and in-service science teachers, thereby, fostering the enactment of open-ended inquiry as practical science.
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Dedication

I dedicate this dissertation to my parents, Hugh and Jean Gastle, who taught me that learning should never end and my husband, Wayne, who started me on this journey.
# Table of Contents

## CHAPTER 1 INTRODUCTION

CHAPTER 2 LITERATURE REVIEW ............................................................... 7

Inquiry-Based Instruction ........................................................................... 7

The Many Faces of Inquiry ......................................................................... 8

Open-Ended Inquiry ................................................................................... 10

Facets of Influence on Teaching Inquiry .................................................... 16

  Teachers’ Views About Teaching and Learning in Science ....................... 16

  Teachers’ Beliefs About Teaching and Learning ...................................... 20

  Types of Teachers’ Knowledge ............................................................... 23

Closing the Gap: Challenges and Program Support ..................................... 25

  Challenges to Enactment ........................................................................ 25

  Program Support for Enactment .............................................................. 30

CHAPTER 3 METHODOLOGY ......................................................................... 36

  Rationale and Study Design ................................................................. 36

  Participants ......................................................................................... 39

    Stage 1 ............................................................................................. 39

    Stage 2 ............................................................................................. 40

    Stage 3 ............................................................................................. 41

  Data Collection ...................................................................................... 41

    Stage 1 ............................................................................................. 41

    Stage 2 ............................................................................................. 43

    Stage 3 ............................................................................................. 44

  Quantitative Analysis ............................................................................ 44

  Qualitative Analysis and Interpretation .................................................. 47

  Trustworthiness ................................................................................... 48

CHAPTER 4 DEVELOPING A FRAMEWORK TO ILLUSTRATE TEACHERS’ REPORTED BELIEFS ABOUT TEACHING AND LEARNING RELATED TO INQUIRY ........................................... 53

  Developing a Tentative Framework ......................................................... 53

  Overview of Quantitative Results ............................................................ 62

  Characterizing Stage 3 Participants ......................................................... 63

    Type 1: Utilitarian Science ................................................................. 64

      Teachers’ Beliefs and Teaching Practices Related to Inquiry ............... 64

      Teachers’ Preferred Practices in Teaching Inquiry .............................. 66

    Summary of Type 1 Themes: Utilitarian Science .................................. 69

    Type 2: Content-Based Science ........................................................... 70

      Teachers’ Beliefs and Teaching Practices Related to Inquiry ............... 70

      Teachers’ Preferred Practices in Teaching Inquiry .............................. 71

    Summary of Type 2 Themes: Content-Based Science ............................ 72

    Type 3: Authentic Contextual Science .................................................. 72

      Teachers’ Beliefs and Teaching Practices Related to Inquiry ............... 72

      Teachers’ Preferred Practices in Teaching Inquiry .............................. 74

    Summary of Type 3 Themes: Authentic Contextual Science ................. 75

    Type 4: Citizenship Science ............................................................... 76

      Teachers’ Beliefs and Teaching Practices Related to Inquiry ............... 76
2. Presents Alternative Strategies for Networking ........................................... 123
3. Teach Teachers to Be Facilitators and Mentors ....................................... 124
4. Develops Confidence and Inspires Teachers ........................................... 125
   Mentors ................................................................................................. 126
Teacher Collaboration and Cooperation ....................................................... 128
Classroom Visitations .............................................................................. 128
On-Line Communication ........................................................................... 129
Teachers-Coaching-Teachers ..................................................................... 131
Funding of Practical Science ..................................................................... 132
   Special Funding for Student Investigations ............................................. 132
A Central Equipment Depot ....................................................................... 133
Textbooks and Other Curriculum Resources .......................................... 134
High Speed Internet .................................................................................. 134
CHAPTER 7 DISCUSSION: WHAT DOES IT ALL MEAN? .............................. 140
   Teachers’ Beliefs and Enactment of Inquiry ........................................... 141
A Framework to Illustrate Dimensionality ............................................... 141
Characterizing Types of Teachers and Applying the Framework .............. 143
Closing the Inquiry Gap: Challenges and Program Support ..................... 147
   Challenges to Enactment of Open-Ended Inquiry ................................ 148
      Personal Challenges ........................................................................ 148
      Contextual Challenges .................................................................... 154
Program Support for Enactment of Open-Ended Inquiry .......................... 156
   Professional Development: Closing the Knowledge Gap ....................... 156
      Types of Professional Development Recommended by Stance .......... 158
      Utilitarian Science ......................................................................... 159
      Content-Based Science .................................................................. 160
      Authentic Contextual Science ........................................................ 161
      Citizenship Science ....................................................................... 161
   Supporting Enactment of Open-Ended Inquiry: Mentors ...................... 163
   Facilitating Teacher Collaboration ..................................................... 165
   Supporting Enactment Through Funding ............................................. 167
CHAPTER 8 WHERE DO WE GO FROM HERE? ............................................. 171
   Implications: Inquiry and the Science Education Community .......... 171
   Limitations of this Study ..................................................................... 174
   Future Directions for Research ......................................................... 176
REFERENCES ......................................................................................... 179
List of Tables

Table 1 Reliability Estimates of Four Composite Scales .......................................................... 55
Table 2 Correlations Between Teacher Belief Items and Belief Factors .................................. 59
Table 3 Correlations Among Summed Scale Scores for Teachers’ Reported Belief Orientations (n=83) .................................................................................................................. 60
Table 4 Teachers’ Beliefs and Teaching Practices, General Themes, and Stances Related to Inquiry .................................................................................................................................. 80
Table 5 Summary of Major Challenges to the Enactment of Open-Ended Inquiry as Practical Work in Science .................................................................................................................................. 111
Table 6 Summary of Major Types of Program Support Recommended for the Enactment of Open-Ended Inquiry as Practical Work in Science .................................................................. 137

List of Figures

Figure 1. A 3-stage mixed methods design .................................................................................. 39
Figure 2. The dimensionality of science teachers’ reported beliefs about teaching and learning that relate to inquiry as practical work in science ........................................................................ 57
Figure 3. Teachers’ beliefs profiles pertaining to teaching and learning and inquiry by dimension.. 58
Figure 4. Characterization of teachers’ beliefs and teaching practices related to inquiry as practical work in science (quantitative and qualitative results) ........................................................................ 87
Figure 5. Challenges to enactment of open-ended inquiry by stance ......................................... 112
Figure 6. Challenges to enactment of open-ended inquiry (all stances) ..................................... 112
Figure 7. Program support by stance related to enactment of open-ended inquiry .................... 139
Figure 8. Program support recommended for enactment of open-ended inquiry by participants from all stances .................................................................................................................... 139

List of Appendices

Appendix A Excerpts from Ontario Curriculum Documents .................................................. 191
Appendix B Ethical Approval ..................................................................................................... 197
Appendix C Consent Forms ...................................................................................................... 194
Appendix D Revised Teachers’ Reported Beliefs Measure ...................................................... 199
Appendix E Interview Protocols .............................................................................................. 204
Appendix F Data Tables ......................................................................................................... 208
CHAPTER 1
INTRODUCTION

Current curriculum documents both nationally and internationally emphasize the importance of teaching open-ended inquiry-based science including the National Science Education Standards (1996); the Benchmarks for Scientific Literacy (American Association for the Advancement of science, 1993), and the Common Framework of Science Learning Outcomes: Pan-Canadian Protocol for Collaboration of School Curriculum (Council of Ministers of Education in Canada, 1997). A similar emphasis on inquiry-based science can be found in each of Ontario’s most recent curriculum documents in science, directing that classroom activities develop in students “the skills, strategies, and habits of mind required for scientific inquiry” (The Ontario Curriculum Grades 11 and 12, 2008, p. 4). Embedded in this emphasis, there is a call for more open-ended types of inquiry that include students developing their investigation skills in science by initiating; designing and conducting investigations; recording, analyzing and interpreting data; and communicating findings (The Ontario Curriculum Grades 11 and 12, 2008, p. 21).

A global emphasis on open-ended inquiry in science (Abd-El-Khalick et al., 2004) is founded on research confirming that students achieve deeper foundational learning, development in problem solving skills and a more sophisticated understanding of the nature of science through the enactment of open-ended inquiry (Abd-El-Khalick et al., 2004; Anderson, 2002; Barrow, 2006; Songer, Lee, & Kam, 2002). With respect to open-ended inquiry in science, the National Research Council (1996) identifies “inquiry into authentic questions generated from student experiences (as being) the central strategy for teaching science” (p. 31).

I approach this study after a lifetime of engagement in open-ended types of inquiry in science from both a personal level and a professional level. My experience, as an undergraduate student
registered in an inquiry-based medical science program, taught me that open-ended inquiry, as practical work in science, can be highly motivating and engaging. Influenced by my own personal experience, I enacted open-ended inquiry as a teacher and found that, just as had been my experience, this approach to practical science motivated and engaged my students. Furthermore, I found that, for many of my students, open-ended inquiry provided a forum within which they could connect directly with the scientific and political world beyond the classroom. In many cases, the findings of their investigations became the basis for successful local and regional political action. Through the years, energized by their investigations, many of my students made the decision to move their classroom-based science projects to the competitive level. Very often, such a decision to communicate their findings to the world of science, and scientists, beyond the classroom door resulted in both regional and national recognition as medals and special awards in science. In addition, for many of my students, engagement in open-ended inquiry became the basis for their decision to pursue science as a career.

Therefore, like Dewey (1910), I firmly believe that science is more than a collection of facts to be memorized and recalled on command. Yet, my experience as a secondary school science teacher, head of science and curriculum leader at the regional level, parallels the statement by the National Research Council (2000) that: “many students (are) mastering disconnected facts in lieu of broader understandings, critical reasoning, and problem-solving skills” (p. 4). Like Schwab (1960), I hold the view that practical science needs to provide all students with the opportunity to discover knowledge which is new to them and, I would add, perhaps, new to the broader scientific world.

In spite of a long-standing call for science as inquiry (Abd-El-Khalick et al., 2004; Dewey, 1910; Rutherford, 1964; Schwab, 1960), research shows that inquiry represents “unfinished business for the science education community” (Keys & Bryan, 2001, p. 651). A large gap continues to be
reported between the visions of teaching and learning in science as presented in curriculum
documents, past and present, and what is enacted within science classrooms (Abd-El-Khalick et al.,
2004; Barrow, 2006; Crawford, 2007). It is my hope that my study will contribute to reducing this
gap in teaching practice related to inquiry.

Research has identified many factors as contributing to the longstanding reticence of teachers
to enact open-ended inquiry-based science including: uncertainty about what open-ended inquiry
might look like in the classroom (Abd-El-Khalick et al., 2004; Anderson, 2002; Blumenfeld,
Krajcik, Marx, & Soloway, 1994; Lederman, 2002; Melville & Bartley, 2010; Minner, Levy, &
Century, 2010; Welch, Klopper, Aikenhead, Robinson, 1981; Windschitl, 2002); teachers’ beliefs,
views and experience in relation to teaching and learning in science (Anderson, 2002; Barrow, 2006;
Crawford, 2007; Krajcik, Marx, & Soloway, 1994); and teachers’ knowledge about how to
effectively facilitate learning in open-ended inquiry (Krajcik et al., 1994). Anderson (2002)
describes three main types of factors that serve as challenges to the enactment of open-ended
inquiry: technical, political, and cultural factors. Anderson (2002) and Barrow (2006) argue that the
lack of open-ended inquiry in science will not be reversed until factors that serve as challenges to
enactment are addressed. My study responds to this concern by first, seeking to identify significant
factors that teachers report as representing challenges to the enactment of open-ended inquiry as
practical science and second, by examining the specific types of program support that teachers
identify as meaningful to the enactment of open-ended inquiry as practical science.

The “dearth of inquiry” (Anderson, 2002) reported in science education is regarded as a
significant problem for curriculum leaders and decision-makers worldwide (Abd-El-Khalick et al.,
2004). Research indicates that open-ended, inquiry-based science is difficult to put into practice
(Anderson & Helms, 2001; Blumenfeld et al., 1991; Crawford, 2007) and that the actions needed to
implement open-ended inquiry-based science in secondary school have many facets requiring varied support for those directly involved (Anderson & Helms, 2001). In addressing these many facets, the National Research Council (1996) argues that a bottom-up view of supporting teacher change would be preferential, stating “teachers know best what they need to learn and be able to do” (p. 80). This mixed method study responds to this stand and the call for research that “elicit(s) the real voices of teachers” (Crawford, 2007, p. 638) as it is grounded in the real lives and expressed views of practicing teachers and, to a large extent, in their own words.

The purpose of this mixed method study is to explore factors that contribute to this recognized gap between the vision of curriculum leaders with respect to inquiry and teaching practice. I will do this by exploring: (a) teachers’ reported beliefs in relation to teaching and learning in inquiry as practical science; (b) teachers’ reported enactment of inquiry as practical science; (c) the factors that teachers report as significant challenges to the enactment of open-ended types of inquiry as practical science; and (d) the specific types of program support that teachers believe would meaningfully facilitate the enactment of open-ended inquiry as practical science at the secondary school level.

The following research questions guided this study:

1. What beliefs do science teachers report that relate to teaching and learning in inquiry as practical science?

2. What types of inquiry do science teachers report enacting in secondary school science?

3. Which factors are reported to represent challenges to the enactment of open-ended inquiry as practical work in science at the secondary school level?
4. According to teachers, what types of program support would facilitate the enactment of open-ended inquiry as practical work in science at the secondary school level?

My hope is that this *enquiry into inquiry* provides insight into issues related to the enactment of open-ended inquiry in science, from the perspective of science teachers’ reported beliefs and practice, which will inform curriculum leaders and decision-makers in such a way as to begin the process of closing this recognized, persistent reported gap between curriculum documents and teaching practice in relation to inquiry. Like Crawford (2007), I believe that the answer resides within the teachers themselves. This research attempts to give *voice* to the teachers, who are charged with the task of enacting open-ended inquiry as practical science, in the hope that, through their ‘voices,’ types of program support will be found that can truly facilitate the enactment of open-ended inquiry at the secondary school level.

In Chapter 2, I outline the theoretical basis for this study. In Chapter 3, I describe the methodology used to generate the quantitative and qualitative data with which to answer the four research questions that guide this study. Chapter 4 presents the results of quantitative and qualitative data analysis and, then, the interpretation of these results by using qualitative findings to confirm and expand on quantitative findings with respect to the first two research questions. In Chapter 5 and 6, I present the analysis and interpretation of qualitative survey and interview data that addresses my third and fourth research questions related to challenges and meaningful program support for enactment of open-ended inquiry in science. In Chapter 7, I discuss the results of this research, generally, and the implications of these results for educational leaders, teacher-educators, and teachers enacting inquiry in science. In addition, I make some suggestions for future research in this area of science education. In Chapter 8, I discuss some implications of this study and make some
recommendations for future directions that research could take in relation to this study. Lastly, I discuss the limitations of this study.
CHAPTER 2
LITERATURE REVIEW

Science is more than a body of knowledge to be learned.
John Dewey (1910)

Inquiry-Based Instruction

Through many years, inquiry has continued to be an important goal of science education (Abd-El-Khalick et al., 2004; Dewey, 1910; Minner et al., 2010; Rutherford, 1964). However, its meaning and purpose has, often, been fraught with confusion and the goal of implementation of inquiry, as an inherent part of science education, has remained elusive (Abd-El-Khalick et al., 2004; Wee, Shepardson, Fast, & Harbor, 2007; Windschitl, 2002; Yager, 2005).

In this chapter, I review the literature to clarify the role of inquiry in science education; explore the meaning of, and types of, inquiry; and consider facets of influence on teaching inquiry. Additionally, I review types of challenges recognized as contributing to this acknowledged gap between the goals for science education with respect to inquiry as presented in curriculum documents and teaching practice and review types of program support identified as fostering the enactment of open-ended inquiry in science.

Affirming that the major aim of science education in Canada is the development of scientific literacy, the Council of Ministers for Canada (1997) identifies open-ended inquiry teaching and learning as a primary means of achieving this aim. The Council reinforces this view by describing scientific literacy as: “An evolving combination of the science-related attitudes, skills, and knowledge 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” (p. 4).
The National Research Council (2000) supports this vision of science education and advises that teaching and learning in science needs to be viewed from two perspectives: (a) the need for teachers to provide learning opportunities designed to develop students’ skills of inquiry such that they are able to both design and carry out scientific investigations; and (b) the need for teaching and learning in science that provides for student mastery of scientific concepts through investigations (p. xv). As such, the National Research Council (2000) is emphasizing an open-ended inquiry-based approach to teaching science that it states connects “learning science, learning to do science, and learning about science” (p. xv). The Council, further, clarifies that open-ended inquiry-based learning includes not only an ability to engage in inquiry, but also, an understanding of how inquiry results in the development of new scientific knowledge.

The Many Faces of Inquiry

Defining inquiry as referring to “the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work” (National Research Council, 1996, p. 23), the Council also describes inquiry as referring to “the activities of students in which they develop knowledge and understanding of scientific ideas as well as an understanding of how scientists study the natural world” (p. 23). Keys and Bryan (2001) confirm that there are many approaches to teaching inquiry described in research.

In support of classifying these approaches to teaching inquiry, Windschitl (2002) reports that researchers have developed “inquiry continua indexed by the degree of independence which students have in asking and answering questions” (p. 114) and identifies four different types of inquiry teaching including: confirmation, structured, guided and open inquiry. Confirmation inquiry (also called ‘cookbook science’) is a very closed-ended type of inquiry which is reported to be the most
predominant form of inquiry (Hofstein & Lunetta, 2004) in science classrooms. This type of inquiry is described as focusing on laboratory exercises as verification, allowing students little independence in inquiry, and involves students following a specified procedure in order to verify previously learned scientific principles (Tafoya, Sunal, & Knecht, 1980; Windschitl, 2002).

Structured inquiry, another largely closed-ended approach to inquiry, offers very little student independence in decision-making where a teacher poses a problem that students will investigate to acquire new, pre-determined learning by following a procedure that has been provided by their teacher (Tafoya, Sunal, & Knecht, 1980; Windschitl, 2002). Guided inquiry is an open-ended approach to inquiry that offers a higher level of student independence in decision-making by providing students with the opportunity to achieve new learning by determining the methods (data collection, analysis and interpretation) that could be applied to successfully solve a problem posed by their teacher (Martin-Hansen, 2002; Tafoya et al., 1980; Windschitl, 2002).

In open inquiry, students have the highest degree of independence, posing the questions that drive their investigations; developing a design for their own investigation; collecting and analyzing data; interpreting their data; and communicating their findings (Martin-Hansen, 2002; Tafoya et al., 1980; Windschitl, 2002). Open inquiry has also been identified as a type of full inquiry (National Research Council, 2000); heuristic problem solving (Bloom, as cited in Ornstein et al., 2003); authentic inquiry (Lederman, 2002; Scheppler, Sethakorn, & Styer, 2003; Schwartz, Lederman, & Crawford, 2004; Weinburgh, 2003); independent inquiry (Windschitl, 2002); collaborative inquiry (Crawford, 2000; Hofstein & Lunetta, 2004; National Research Council, 1996); student-directed, open-ended inquiry (Bencze, Bowen, & Alsop, 2006); and question-driven, problem-based learning (Chin & Chia, 2004) where the focus is on discovering scientific knowledge on a topic relevant to the individual student and not previously determined by the teacher.
Martin-Hansen (2002) adds a fifth approach of inquiry, designated as coupled inquiry, which is also presented as a very open-ended type of inquiry. Coupled inquiry is described by Martin-Hansen (2002) as a two-stage process with guided inquiry as the first stage and open inquiry as the second stage. During guided inquiry, students receive training in the specific skills of inquiry which are, then, applied to their own investigations that follow during open inquiry.

Of the four different types of inquiry described in research, open inquiry has been identified as a priority for science education (Abd-El-Khalick et al., 2004; American Association for the Advancement of Science, 1990; National Research Council, 1996). The National Research Council (1996) maintains that science education should include: “inquiry into real questions generated from students’ experiences (as) the central strategy for teaching science” (p. 21) and that students should “develop a capacity to conduct complete inquiries” (p. 23). In Canada, a parallel emphasis on open-ended inquiry can be found in the foundation statements of the Common framework of Science Learning Outcomes (Council of Ministers of Education, 1997) from which Ontario’s Curriculum documents in science were developed (Minister of Education of Ontario, Press conference, March 30, 1998). This same emphasis has been retained in the Ministry’s latest curriculum documents in secondary school science (Ministry of Education, 2008). Given the centrality of open-ended inquiry (and the confusion around its definition), I have focused research questions 1 and 2 on open-ended inquiry.

**Open-Ended Inquiry**

Researchers report that confusion exists among teachers and teacher-educators as to what open-ended inquiry is and how it would appear in the classroom (Abd-El-Khalick et al., 2004; Barman, 2002; Barrow, 2006; Martin-Hansen, 2002; Melville & Bartley, 2010; Minner, Levy, &
Century, 2010; Minstrell & van Zee, 2000). The National Research Council (2000, p. 29) provides some pedagogical clarity for this situation by identifying five essential features that would characterize classroom inquiry including students: (a) engaging scientifically oriented questions; (b) giving priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions; (c) formulating evidence-based explanations to answer scientifically oriented questions; (d) demonstrating scientific understanding by evaluating their explanations in light of alternative explanations; and (e) communicating and justifying their proposed explanation(s). Minner et al. (2010) maintain that a sixth feature of classroom inquiry is included in the Standards (National Research Council, 1996): learners designing and conducting investigations.

Within its framework, the National Research Council (2000) distinguishes between two types of inquiry, partial and full inquiry (p. 28). In partial inquiry, one or more of the essential elements is missing while in ‘full’ inquiry, all five of the essential elements of classroom inquiry are present. The National Research Council (2000) places priority on full inquiry maintaining that, in science, classroom inquiry needs to provide students with opportunities to develop their abilities “to design and conduct scientific investigations” (p. xv) in support of developing student understanding of the nature of scientific inquiry and how scientific inquiry connects with the process of discovery and the development of scientific knowledge (National Research Council, 1996).

With reference to the four types of inquiry in the continuum (confirmation, structured, guided, and open inquiry), the National Research Council (2000) identifies guided and open inquiry as types of full inquiry and indicates that the difference between these two types of open-ended inquiry derives from the “degree to which teachers structure (direct) what students do” (p. 29). In guided inquiry the problem to be investigated is posed by the teacher, whereas in open inquiry, the
problem being investigated is posed by the student. Since both guided and open inquiry incorporate the five essential features that characterize classroom inquiry (National Research Council, 2000), these types of inquiry would, therefore, be categorized as types of full inquiry. Coupled inquiry, as described by Marten-Hansen (2002) which includes open inquiry, could also be classified as a type of full inquiry.

In this study, to resolve some of the additional confusion that is associated with the term ‘open’ inquiry (Lock, 1990) will add a descriptor and use the term ‘fully’ open inquiry to refer to a type of inquiry where students identify and pose a problem in a scientific topic of interest to them and, then, design, plan and carry out an investigation to solve the problem, interpret their data using models and explanations, and communicate the results to others in written and/or oral form. Use of the descriptor ‘fully’ draws on the National Science Council’s (2000) classification of inquiry as full or partial. As described earlier (see page 11), this type of inquiry incorporates each of the essential features of full inquiry and corresponds to the descriptions of open inquiry found in the literature (Martin-Hansen, 2002; Windschitl, 2002). In addition, inquiry that is ‘fully open’ implies independent, student-directed inquiry in all stages of inquiry where the role of the teacher, during inquiry, would be facilitator and mentor. The designation ‘fully open inquiry’, therefore, connects with the classification of types of inquiry based on the level of student independence (confirmation, structured, guided or open) (Tafoya, Sunal, & Knecht, 1980; Windschitl, 2002) and with the categorization of inquiries by the National Research Council (2000) as full or partial.

In describing enactment of inquiry, the National Research Council (1996) supports a high level of student independence. The Council describes inquiry as:

a multifaceted activity that involves (students) making observations; posing questions; examining books and other sources of information to see what is already known in light of experimental evidence; using tools to gather, analyze, and interpret
This description of inquiry includes the goal of students posing questions that drive their investigations. As such, the National Research Council (1996) is emphasizing the enactment of fully open inquiry maintaining that: “fruitful inquiries evolve from questions that are meaningful and relevant to students” (National Research Council, 2000, p. 24). The Council (1996) characterizes open-ended inquiry as an active process that requires active participation of the learner and as such is regarded as a ‘hands-on’ and a ‘minds-on’ process. Additionally, Abd-El Khalick et al. (2004) report that inquiry in the National Science Education Standards is presented as both means and ends. “Inquiry as means” (Abd-El Khalick et al., 2004, p. 2) is identified as students’ doing inquiry where inquiry is the vehicle for facilitating understanding of subject matter. Therefore, science content is the educational goal. Conversely, “inquiry as ends” (Abd-El Khalick et al., 2004, p. 2) is identified as an approach to teaching and learning where inquiry is the educational goal with students doing inquiry to develop epistemological understandings about the nature of science and the development of scientific knowledge and develop their investigative skills. As such, teaching and learning in inquiry becomes both process and product.

Kahle (1996) maintains that, in their emphasis on open-ended inquiry, the National Science Education Standards (National Research Council, 1996) are calling for science educators to guide and support students in active, extended inquiry. In the implementation of extended, fully open inquiry as a teaching strategy, project-based science (Krajcik, Blumenfeld, Marx, & Soloway, 1994; Singer, Marx, & Krajcik., 2000) can be enacted with students investigating a topic area of interest to them. Brophy (2004) states “There are two essential components to projects: 1) They require a question or problem that organizes and drives activities; and 2) The activities result in a series of products that culminate in a final product that addresses the driving question” (p. 237). Marx et al.
(1994) refer to these products as artifacts identifying them as “tangible, real results of the process of investigation that represent student understanding” (p. 345). These artifacts can be communicated and critiqued by the teacher, peers, and others to support their revision in a mastery orientation (Bloom, as cited in Ornstein et al., 2003). In the literature, other types of open-ended inquiry are described which are very similar to the description of project-based science as presented by Krajcik, Blumenfeld, Marx, & Soloway (1994) and Singer, Marx, & Krajcik (2000). Included this group are problem-based learning (Blumenfeld et al., 1991; Chin & Chia, 2004); problem-based science (Marx et al., 1997); problem-based inquiry (Marx et al., 1997); project-based instruction (Blumenfeld et al., 1994; Krajcik et al., 1994); project-based inquiry (Blumenfeld et al., 1991); and student-directed, open-ended project-based scientific inquiry (Bencze, Bowen, & Alsop, 2006).

Arguing that students need to solve ‘authentic’ problems in science that are meaningful to them, Blumenfeld et al.’s (1991) description of the process of project-based inquiry can equally be applied to fully open inquiry including students posing and refining problems; designing experiments or other data gathering plans; collecting and analyzing data; drawing data-based conclusions; creating products; and communicating findings to others. In project-based (fully open) inquiry, students develop expertise in a topic of interest to them that potentially provides them with the opportunity to communicate their findings, knowledgeably and confidently, to many different audiences including peers, teachers, parents, administrators, and perhaps to significant members of a broader community.

Maintaining that learning should be an enjoyable enterprise for students as well as teachers, Brophy (2004) states that a teacher “can tap into the motivational potential of students’ individual interests by incorporating them into the curriculum” (p. 244) and acknowledges the role that project-based inquiry can play in relation to this goal of engaging students in learning that is intrinsically
motivating. Moje et al. (2001) confirm that project-based inquiry is often offered as pedagogy in support of the educational goal of engaging all students in learning and, therefore, as a means of providing “science for all” (National Research Council (1996, p. 7). In that spirit, many reformers, according to Van Zee et al. (2003), have recommended a shift to project-based inquiry.

In spite of a general call for open-ended types of inquiry in science as guided or fully open inquiry (National Research Council, 2000) by curriculum developers both nationally and internationally, research broadly supports the observation of Abd-El Khalick et al. (2004) that: “what is enacted in classrooms is mostly incommensurate with visions of inquiry put forth in reform documents” (p. 398). Additionally, research indicates that, in classrooms where inquiry teaching and learning is taking place, confirmation and structured inquiry are the norm (Windschitl, 2002) with confirmation inquiry predominating (Hofstein & Lunetta, 2004; Yager, 2005). Further evidence for this trend, can be found in a report prepared by the Council of Ontario Universities for the Ministry of Education (2006) where a “weakness in problem-solving” (p. 2) is identified along with a tendency in Ontario’s High School graduates to approach problem solving through rote memorization.

Clearly, teaching and learning in science must change if current curricular goals for science education are to be achieved. My investigation seeks to address this concern by, first, exploring teachers’ reported beliefs and practices with regard to inquiry and, secondly, exploring factors that represent challenges to teachers’ enactment of open-ended inquiry in science. Lastly, this investigation seeks to identify specific types of program support that teachers report can contribute to correcting this identified gap in teaching practice.
Facets of Influence on Teaching Inquiry

*Teachers’ Views About Teaching and Learning in Science*

Research indicates that teachers’ views, or orientations, about education influence decision-making and teaching practice, including the implementation of science curriculum (Brickhouse, 1990; Southerland, Gess-Newsome, & Johnston, 2003) and the enactment of open-ended inquiry in science (Crawford, 2007; Luft, 2001). Studying four secondary school biology teachers, Friedrichsen and Dana (2005) confirmed that science teachers’ views, or orientations, about science are derived from the interplay of their beliefs and knowledge in relation to teaching and learning in science. In addition, they report that classroom context and beliefs about learners and their learning strongly influenced the teaching orientations of these teachers.

Gallagher (1991) argues that the lack of willingness of teachers to teach open-ended inquiry and their failure to appropriately “characterize scientific knowledge as tentative, and scientific work as creative” (p. 132) is the result of the failure of their own education to emphasize the processes by which scientific knowledge is discovered (the Nature of Science or NOS) [A full review of NOS is beyond the scope of this thesis. For more information about NOS please refer to Lederman (1999) and Pedretti and Little (2008).] Support for the position that teachers’ lack of willingness to teach open-ended inquiry is related to failure of their own education to emphasize the nature of science can be found in Windschitl’s (2002) study of six students in a teacher education program of whom three identified significant prior experience doing open-ended inquiry. In spite of direct training in 'doing' open-ended inquiry during their teacher training program, he reports that the three pre-service teachers who enacted open-ended types of inquiry during practice teaching were the pre-service teachers reporting significant personal experience in their undergraduate training, or as professionals prior to their teaching training.
Two opposing science teachers’ views, or orientations, are reported in research including: (a) a knowledge-transmission orientation characteristic of a traditional view of teaching; and (b) a learning-facilitation orientation characteristic of a constructivist view of teaching, each with its own cluster of beliefs (or belief system) (Gow & Kember, 1993). Therefore, as I began this study, I considered that teachers’ views, or orientations, about teaching and learning related to inquiry would be dichotomous with teachers holding a knowledge-transmission view or a learning-facilitation view.

Teachers holding a knowledge-transmission or traditional view of science (Windschitl, 1999) are reported to regard scientific knowledge as a static, logical and systematic collection of facts (Wallace, Tsoi, Calkin, & Darley, 2003; Stipek, Givvin, Salmon, & MacGyner, 2001) and, therefore, additive and infallible (Roth & Roychoudhury, 2003). They are also reported to view classroom experimentation as objective data gathering for the purpose of verification. As such, many of these teachers implement science as confirmation (‘recipe’ or ‘cookbook’) labs supported by printed materials, most often a textbook. In ‘cookbook’ or ‘recipe’ labs, the purpose of the investigation is clearly identified along with the procedure for conducting it and questions to direct data analysis (Saunders, 1992). All steps, in every stage of the investigation, are determined by someone other than the students doing the investigation.

Research reports that in a knowledge-transmission orientation or traditional view of learning in science, the primary role of the teacher becomes transmitting scientific knowledge, as proven facts and absolute truths, which students memorize in rote fashion (Roth & Roychoudhury, 2003; Wallace et al., 2003). Haberman (1991) characterizes this orientation to teaching and learning in science as “the pedagogy of poverty” (p. 291). The learning environment, in a knowledge transmission orientation, is reported to be teacher-directed and content-centered with the highest priority, in
curricular decision-making, placed on finishing the course (Entwistle & Walker, 2002, Roth & Roychoudhury, 2003) and covering the content in the textbook (Gallagher, 1991). Teachers holding this view of teaching and learning are reported to be academically oriented (Melville & Wallace, 2007) communicating belief in the importance of being an authority (subject matter specialist) and being in control of both their students’ learning and behavior (Entwistle & Walker, 2002; Melville & Wallace, 2007). Efficiency, as effectiveness, is identified as driving their teaching practice (Stipek, Givvin, Salmon & MacGyners, 2001). Additionally, teachers holding a knowledge-transmission view of teaching and learning are reported to regard evidence for academic proficiency as students' memorization of facts and concepts transmitted to them as “certain knowledge” (Hofer & Pintrich, 1997) or “revealed truth” (Gallagher, 1991, p. 123) and the accurate reproduction of this information on a test or exam (Wallace, Tsoi, Calkin & Darley, 2003).

In comparison, Abd-El-Khalick et al. (2004) argue that open-ended inquiry and a learning-facilitation or a constructivist approach to teaching and learning share many educational objectives. Constructivism is a philosophy of learning that assigns primary importance to the way in which learners attempt to make sense of what they are learning. This philosophy of learning is strongly associated with the theoretical position of John Dewey (1910) who asserted that learning develops from direct personal experience and that knowledge emerges from the interaction between the student and sensory input from his or her external environment. Based upon prior learning, Dewey believed that students respond to sensory input by constructing cognitive structures or schemas as new learning that represent their current personal understanding of the world (Dewey, 1910). Saunders (1992) identifies these cognitive structures or schemas as one’s beliefs, understandings, and explanations (subjective knowledge) of the world and identifies two important uses for these
cognitive structures by students: (a) providing the potential to make predictions based upon their past experiences; and (b) providing a basis for developing explanations for their predictions.

Applying this philosophy to the enactment of open-ended inquiry would mean that a teacher would regard learning in science as a “psychologically active process” (Saunders, 1992, p. 137), in which a student constructs and reconstructs her/his subjective knowledge of the world during the investigative process. The image becomes students, as individuals, actively engaging their cognitive processes, investigating, and collaborating with others in small or large groups individually constructing their own knowledge facilitated by their teacher (Minner, Levy & Century, 2010; National Research Council, 1996; Roth & Roychoudhury, 2003; Windschitl, 1999). The National Research Council (1996) recognizes the importance of social interaction to the learning process in stating: “knowledge is actively constructed by a student through a process that is individual and social” (p. 32). The Council further directs science teachers to implement teaching strategies in an open-ended approach to inquiry that “nurture a community of science learners” (p. 26).

In support of such a dynamic and interactive approach to learning, science teachers need to be able to provide a learning environment that is ‘rich’ with respect to resources and technology. The importance of classroom context to student learning in open-ended inquiry is recognized by Rieber (1993) who reports that: “constructivists assert that there is a direct relationship between learning and the degree to which the environment supplies a rich source of engaging experiences” (p. 197). In addition, Friedrichsen and Dana (2005) also report that classroom context has been found to strongly influence the development of teaching orientations which in turn have been reported to influence teaching practices (Crawford, 2007; Luft, 2001; Southerland, Gess-Newsome, & Johnston, 2003). In the goal of fostering teachers’ enactment of open-ended inquiry, Crawford (2007) asserts that: “It is important to examine a teacher’s conception (view) of inquiry” (p. 637) but, also, maintains that
such studies must include a teacher’s context of practice. My study responds to Crawford’s position by including the examination of science teachers’ views of teaching and learning in relation to inquiry and their reported enactment of inquiry in relation to their teaching context.

Research indicates that science teaching is primarily traditional in nature (Minner, Levy & Century, 2010; Roth & Roychoudhury, 2003; Yager, 2005; Verjovsky & Waldegg, 2005). For many teachers, then, the decision to implement open-ended inquiry in science would mean a conceptual shift from a teacher-directed, content-oriented approach to teaching (associated with a traditional knowledge-transmission or positivist view of learning science) to the student-directed, learning-oriented approach to teaching (associated with a learning-facilitation or constructivist view of learning science) (Entwistle & Walker, 2002). Such a conceptual shift, also, requires a pedagogical shift from a textbook-based teaching and learning style, in which the teacher strives for full control of student learning to open-ended inquiry in which the teacher facilitates active student learning. Stipek, Givvin, Salmon and MacGyners (2001) warn: “This shift is not made easily” (p. 214).

**Teachers’ Beliefs About Teaching and Learning**

Teachers’ beliefs about inquiry are identified as a primary basis on which they adopt or reject inquiry teaching and learning theories and practices (Keys & Bryan, 2001; Zhang et al., 2003). Beliefs have been described as “personal cognitive constructs accepted as true by the individual holding the belief with episodic roots based on personal experiences” (Kanari & Miller, 2004, p. 465). Research reports that teachers’ beliefs are the basis of action (Crawford, 2007; Haney, Lumpe, Czerniak, & Egan, 2002; Luft, 2001; Stipek et al, 2001; Wallace & Kang, 2004)); influence teachers’ decisions and judgments (Kane, Sandretto, & Heath, 2002; Keys & Bryan, 2001; Pajares, 1992); and serve as a filter for accepting or rejecting new information (Kane, Sandretto, & Heath., 2002; Pajares, 1992; Wallace & Kang, 2004).
Parjares (1992) states that beliefs “vary along a central-peripheral dimension” (p. 318) with central beliefs being more stable and resistant to change (Yerrick, Parke, & Nugent, 1997) and, therefore, more influential in affecting behavior. Luft (2001) provided evidence reinforcing the notion that teachers’ beliefs are stable and resistant to change. Studying the impact of an open-ended inquiry-based professional development program on the beliefs and practices of 14 middle and secondary science teachers, she reports that teachers’ practices changed but there was not a statistically significant change in their beliefs. Luft (2001) states: “While participants’ beliefs may have directed their inquiry practices, their inquiry practices did not noticeably affect their beliefs” (p. 530).

Parjares (1992) asserts that beliefs are a legitimate subject of study. This follows the studies of Nespor (1987) who posits that beliefs influence how we experience the world around us and what we learn from our experiences. Furthermore, in influencing learning, she suggests that beliefs are more strongly affective and evaluative than knowledge. Citing the studies of Ernest (1989), Pajares (1992) reports that beliefs may be more useful in understanding and predicting teachers’ decision-making than teacher knowledge. Haney et al. (2002) studied the belief structures of four prospective teachers qualitatively through direct observation of their teaching practices, reflective journals, lesson plans and interviews to examine the relationship between teachers’ beliefs and action. Their study provided evidence that teachers’ beliefs do influence their decision-making and subsequent classroom action. Crawford (2007) provides additional direct evidence that teachers’ beliefs affect their decision-making and teaching practices in her study of one high school biology teacher actively engaged in teaching open-ended inquiry.

Clusters of beliefs are, further, reported to connect to form attitudes that become the basis of action as ‘action agendas’ during goal-directed behavior (Haney et al., 2002; Pajares, 1992). Pajares
(1992) maintains that teachers’ belief systems form from their particular clusters of beliefs, attitudes and values (i.e., beliefs that take on evaluative, comparative and judgmental functions). He states “beliefs are the best indicators of the decisions individuals make throughout their lives” (p. 307) and argues that, to improve teachers’ practices, it is essential to understand teachers’ belief structures. Therefore, beliefs and clusters of beliefs that science teachers hold about teaching and learning that relate to inquiry can be considered as central to the aim of facilitating teacher change in relation to the enactment of open-ended inquiry as practical science (Crawford, 2007). My study incorporates this view.

A broad base of research indicates that teachers’ beliefs about teaching and learning affect their teaching practices (Cronin-Jones, 1991; Eick & Reed, 2002; Fang, 1996; Hativa & Goodyear, 2002; Southerland, Gess-Newsome, & Johnston, 2002; Stipek et al., 2001; Wallace & Kang, 2004). Haney et al. (2002) identify two types of beliefs as being critical to teachers’ decision-making in relation to goal-directed behavior such as the enactment of open-ended forms of inquiry as practical science: capability or self-efficacy beliefs and context beliefs. Capability or self-efficacy beliefs focus on a teacher’s beliefs that he/she has the skills and knowledge necessary to function effectively. Bandura (1977) identifies two types of self-efficacy beliefs: outcome expectancies (i.e., the belief that specific teaching behavior will lead to the target outcome) and efficacy expectancies (i.e., the belief that the specific behavior needed to produce the target outcome can be successfully performed). He maintains that efficacy expectations determine “how much effort people will expend, and how long they will persist in the face of obstacles and aversive experiences” (p. 194). Research indicates that a perception of strengthened self-efficacy yields greater effort and persistence (Bandura, 1977). Efficacy expectations are reported to be highly resistant to change even when experience is contrary (Bandura, 1977).
Context beliefs would include factors external to the science teacher (e.g., technological support, resource support, administrative support) which are necessary to support a teacher’s effective functioning in relation to the enactment of open-ended inquiry. Haney et al. (2002) report that teachers with high capability, or self-efficacy, and high context beliefs are more likely to design lessons that incorporate inquiry and are more likely to reach target goals than teachers with low self-efficacy and low context beliefs. In identifying types of program support to meaningfully facilitate the enactment of open-ended forms of inquiry in science, a focus of investigation must be the search for ways to enhance teachers’ self-efficacy and context beliefs.

Therefore, I am approaching this study from the theoretical position that teachers’ beliefs do influence their teaching practices and that examining teachers’ beliefs provides insight into teachers’ decision-making. Additionally, in examining the reported beliefs of practicing science teachers related to teaching and learning in inquiry, I am responding to the position of Parjares (1992) who argues that the study of teachers’ beliefs can and should be a focus for educational research. Lastly, I am responding to the position of Keys and Bryan (2001) who call for research centred on teachers’ beliefs related to inquiry which may contribute to bridging the gap between theory and teaching practice in this important area of science education.

Types of Teachers’ Knowledge

Fang (1996) indicates that knowledge forms a system of beliefs and attitudes which direct perceptions and teacher practice. Several types of teacher knowledge are identified in research including: content or subject knowledge; pedagogical knowledge; pedagogical content knowledge; and personal practical knowledge (Elbaz, 1991; Fang, Sandretto, & Heath, 2002; Johnston, 1992; Ormond & Cole, 1996; Shulman, 1987).
Shulman (1986) links effective teaching to three of these types of knowledge: content or subject knowledge; pedagogical knowledge; and pedagogical content knowledge. Whereas content or subject knowledge is described as specific scientific knowledge to support teaching and learning in science (Friedrichsen & Dana, 2005), pedagogical knowledge is described as knowledge about general teaching strategies (Ormond & Cole, 1996). Pedagogical content knowledge (PCK) is described as knowledge about teaching strategies for teaching certain subject matter to students (Ormond & Cole, 1996). PCK is identified as being experienced-based, expert knowledge (Shulman, 1986) which incorporates teachers’ content or subject knowledge; pedagogical knowledge and knowledge about learning (Loucks-Horsley & Matsumoto, 1999). Posnanski (2002) includes knowledge about assessment strategies; contextual factors that impact on teaching; and educational reform as aspects of pedagogical content knowledge.

Each of these three types of knowledge is identified as being significantly involved in teacher decision-making and teaching behavior (Nespor, 1987; Ormond & Cole, 1996). Friedrichsen and Dana (2005) reported that pedagogical content knowledge has been proposed as a means for understanding the relationship between science teachers’ beliefs and knowledge and their classroom practice. Crawford (2000) concluded that open-ended inquiry requires a high level of pedagogical content knowledge including understanding of how to collaborate with students and how to mentor and facilitate student investigations. In effective teacher development to support the enactment of open-ended inquiry, Friedrichsen and Dana (2005) report that pedagogical content knowledge must connect a teacher’s content knowledge with his/her pedagogical knowledge.

Personal practical knowledge is also reported to be significant in guiding teacher decision-making and behavior (Wallace & Kang, 2004). Kane, Sandretto, and Heather (2002) describe personal practical knowledge as context-specific, school-based knowledge accumulated through a
teacher’s first hand, classroom-based practice in the management of students including knowledge about students’ interests, needs, learning styles, strengths and difficulties. Personal practical knowledge is reported to “reside at the centre of teachers’ professionality” (Van Driel, Beijaard, & Verloop, 2001, p. 142) and is also reported to include teachers’ personal experiences, past and present, and future plans that relate to teaching practice (Connelly & Clandinin, 1987). Van den Berg (2002) maintains that “(personal) practical knowledge of teachers guides their behavior and that the meanings they attribute to themselves, the situation, and others are of critical importance to their teaching” (p. 592).

Beliefs are reported to be an important part of personal practical knowledge and serve as a filter for the development of new personal practical knowledge (Wallace & Kang, 2004). Wallace and Kang (2004) argue that highlighting teachers’ constructed description of inquiry and the purposes for which they teach inquiry in science will provide keys to understanding the belief conditions significant to teaching different types of inquiry in science. My study responds to this position by asking teachers to describe their inquiry practices in science and their purposes for teaching inquiry.

**Closing the Gap: Challenges and Program Support**

*Challenges to Enactment*

The National Research Council (1996) emphasizes the implementation of open-ended inquiry as practical work in science. Studies show that the majority of teachers resist and do not teach open-ended inquiry (Cronin-Jones, 1991; Keys & Kennedy, 1999; Kleine et al., 2002). Many factors have been identified as contributing to teachers’ resistance including personal factors and contextual factors (Krajcik, Blumenfeld, Marx & Soloway, 1994). Personal factors identified as significant in
research include: teachers’ beliefs and values related to teaching and learning in science; teachers’ personal classroom experiences both as teachers and as students of science; teachers’ content knowledge and pedagogical content knowledge in relation to organizing and maintaining a constructivist-based classroom environment in science; and a lack of deep understanding about the nature of science (NOS) (Anderson, 2002; Barrow, 2006; Bencze & Hodson, 1999; Blumenfeld et al., 1991; Brown, Abell, Demir, & Schmidt, 2006; Keys & Bryan, 2001; Krajcik et al., 1994; Marx et al., 1997; Shin, Yager, Seok, & Lee, 2003; Southerland, Gess-Newsome, & Johnston, 2002; Zhang et al., 2003).

Additional personal factors reported in research as representing challenges to the enactment of open-ended inquiry include: a lack of teacher knowledge about open-ended inquiry (Abd-El-Khalick et al., 2004; Windschitl, 2002); a lack of teacher confidence in the effectiveness of student learning in open-ended inquiry (Keys & Kennedy, 1999; Kleine et al., 2002); teacher efficacy beliefs related to implementing effective strategies to achieve desired learning outcomes (Tschannen-Moran, Hoy, & Hoy, 1998); teacher efficacy beliefs concerning effective management of classes during open-ended inquiry in science (Baker, 2002; Tschannen-Moran et al., 1998); and teachers’ beliefs about constraints that impede implementation of open-ended inquiry (Keys & Bryan, 2001; Songer, Lee, & Kam, 2002).

Contextual factors identified as challenges include classroom limitations (e.g., large class size, inadequate classroom space, teacher mobility); institutional limitations (e.g., a lack of instructional freedom, budget issues, outdated resources, safety issues); a lack of equipment to adequately support student investigations; technological limitations (including unreliable internet connectivity); administrative support; student attitudes; and inadequate preparation time (Brickhouse
& Bodner, 1992; Davis & Falba, 2002; Haberman, 2002; Huang, 2006; Keys & Kennedy, 1999; Marx et al., 1997; Songer, Lee, & Kam, 2002).

Research indicates that the way teachers deliver curriculum is strongly influenced by context, most particularly by school-level environmental factors (Huang, 2006). Research also indicates that teachers’ perceptions are useful in determining environmental factors that influence teachers’ behavior (Anderson, 1982). While recognizing that perceptions could be criticized as lacking objectivity, Huang (2006) reports that the use of more objective indicators has proven to be difficult. In support of educational change, Huang (2006) argues that investigating science teachers’ views of their teaching environments is an important starting point for identifying the current status of secondary school teaching context in science. She adds that it is “crucial to understand these contexts and, in particular, what teachers judge to be the less satisfactory aspects, in order to foster school environments more conducive to science teaching and learning” (p. 41).

As already discussed in an earlier section of this literature review, teachers’ views about open-ended inquiry and its perceived difficulty present a challenge for teachers (Krajcik et al., 1994; Welch, Klopper, Aikenhead & Robinson, 1981). An additional challenge is reported to be largely associated with the current emphasis in science on “a didactic chalk-and-talk approach coupled with occasional verification-type laboratory exercises” (Abd-El-Khalick et al., 2004, p. 401). Marx, Blumenfeld, Krajcik & Soloway (1997), like Entwistle and Walker (2002), report that teachers experience significant discomfort in shifting from a teacher-directed, knowledge-transmission approach to a student-directed, learning-facilitation approach to teaching and learning in science that is characteristic of teaching open-ended inquiry. In doing so, Marx et al. (1997) indicate that the teachers need to address feelings of uncertainty that come with the role of being a novice once again.
Included in the challenges related to the teaching of inquiry is the difficulty that teachers face in motivating students to maintain sustained cognitive engagement and to take responsibility for their own learning (Krajcik et al., 1994). Additionally, research reports teacher confusion about what open-ended inquiry is and what an open-ended, inquiry-based classroom might look like (Marx et al., 1997; Melville & Bartley, 2009; Minner et al., 2010; Wee et al., 2007; Zhang et al., 2003). A teacher’s past personal educational history in science, during which research indicates many of their beliefs in relation to teaching and learning in science were formed, is also identified as potentially presenting a significant challenge to the enactment of inquiry for many teachers (Luft, 2001).

Teachers’ training in science at university or college is generally reported to be limited to confirmation labs (Hancock, Kaput & Goldsmith, 1992; Windschitl, 2002). Schwab (2000; 1964) argues that: “A teacher whose own study has been dogmatic and doctrinaire will be unprepared to teach science as enquiry” (p. 26).

Anderson (2002) contributes further perspective with respect to challenges related to enactment of open-ended inquiry. In reporting on results of cross-case analysis of a set of related case studies, he indicates that challenges to enactment clustered into three dimensions including: a cultural dimension, a technical dimension, and a political dimension. The cultural dimension, Anderson (2002) maintains, is “possibly the most important because beliefs and values are so central to it” (p. 8). Issues related to textbooks, assessment, and the preparation of students for future challenges are included in this dimension.

Challenges in the technical dimension are reported by Anderson (2002) to include issues related to teachers’ context beliefs; conflicting priorities and commitments; student assessment; personal practical knowledge; teacher and student roles; and inadequate training. Challenges in the political dimension are reported to include: a lack of in-service preparation; parental resistance;
collegial tension; lack of resources; and issues of justice and fairness. Anderson (2002) states, “what this research tells us is that the task of preparing teachers for inquiry teaching is much bigger than the technical matters” (p.8). Barrow (2006) maintains that Anderson’s challenges will need to be dealt with before the goal of enactment of open-ended types of inquiry in science can be achieved.

In spite of a long-standing call, both nationally and internationally, for teaching in science that includes the implementation of open-ended forms of inquiry in science, teaching and learning in science continues to fall far short of this goal (Abd-El-Khalick et al., 2004; Crawford, 2007; Haberman, 1991; National Research Council, 2000; Yager, 2005). Although research confirms that many teachers could teach open-ended inquiry in science (Anderson, 2002), research indicates that carrying out this type of science instruction is difficult for teachers (Anderson & Helms, 2001; Blumenfeld et al., 1991). As is the case with other researchers in education, Krajcik et al.(1994) argue that open-ended forms of inquiry will not be widely adopted unless educational researchers and leaders identify the factors that serve as challenges to teachers’ enactment of these types of inquiry in science and find specific ways to support teachers as they endeavor to overcome these challenges. In my study, I first identify teachers’ perceptions of current shortfalls that represent challenges to their implementation of open-ended inquiry and secondly, determine types of contextual changes that would support a shift in their teaching practice to enactment of open-ended inquiry. Thirdly, I report on a large percentage (80%) of secondary school science teachers currently employed by Pine Valley School Board.

My study seeks to identify factors that serve as challenges to teachers’ enactment of open-ended inquiry in secondary school science. In this study, I contribute to the literature by addressing teachers’ needs in one public school board district (Pine Valley School Board), comprising 104 science teachers teaching Grades 9 to 12, with respect to the types of inquiry the teachers report
implementing in their classes, paying particular attention to the enactment of open-ended inquiry. Part of this study also explores types of program support that teachers in Pine Valley School identify as meaningful to their enactment of open-ended inquiry as practical science.

**Program Support for Enactment**

Lessons from the past indicate that open-ended inquiry will not be widely adopted in science unless (a) an attempt is made to recognize areas of difficulty that represent challenges to implementation of open-ended inquiry, and (b) attention is paid to finding specific ways of supporting teachers as they endeavor to enact open-ended forms of inquiry (Blumenfeld et al., 1991; Davis & Falba, 2002; Krajcik et al., 1994). Davis and Falba (2002) maintain that this is key to successfully incorporating reform related to inquiry in science classrooms. The National Research Council (1996) advises that if success is to be achieved in the goal of finding specific ways of supporting teachers in relation to the enactment of open-ended inquiry in science, the teachers themselves must be consulted as they can best identify their needs and provide insight into how these needs can be addressed.

As indicated earlier, the enactment of open-ended inquiry will require substantial changes in teacher thinking and instructional practices and these changes are reported as being difficult to achieve (Blumenfeld et al., 1991; Wee, Shepardson, Fast & Harbor, 2007). Songer, Lee, and Kam (2002) recommend that professional development in support of fostering the implementation of open-ended inquiry-based science should “center on enacted curriculum focused on changing teacher beliefs” (p. 712). Anderson (2002) concurs maintaining that teachers’ beliefs are important to teacher change. Additional support is found in the report by Zhang et al. (2004) who indicated that changes in beliefs were seen to precede changes in practice.
Haberman (1991) advises: “Good teaching is a process of drawing out rather than stuffing in” (p. 294). Professional development to support the enactment of inquiry that incorporates this vision of ‘good teaching’ would focus instruction on incorporating teachers’ meanings (beliefs, attitudes, and emotions) rather than coverage (Van den Berg, 2002). Research indicates that this type of professional development should be led by a skilled facilitator (Van den Berg, 2002) who identifies conditions under which open-ended science could emerge and recognizes that teacher behavior is context-specific (Huang, 2006). Krajcik et al. (1994) advise that such initiatives need to take teachers’ knowledge and experience into account.

Research indicates that professional development designed to support the enactment of open-ended inquiry-based science needs to focus on the real world of the classroom (Anderson, 2002; Crawford, 2007; Krajcik et al., 1994; Luft, 2001; Melville & Wallace, 2007) and incorporate practical investigative activities and approaches that could be readily used, with success, in a classroom (Anderson, 2002; Crawford, 2007; Loucks-Horsley & Matsumoto, 2003; Marx et al., 1994; Melville & Wallace, 2007). In addition, Davis and Falba (2002) advise that such staff development should also incorporate technology and applications of technology that are important to open-ended types of inquiry.

The vision of inquiry-based science in curriculum documents is that of teaching and learning in science as an active and dynamic process (National Research Council, 1996; Council of Ministers of Education in Canada, 1997; Ministry of Education, 1999). Learners construct knowledge while investigating meaningful questions which they have posed (Minner, Levy & Century, 2010; National Research Council, 1996; 2000) concluding with communication of learning (Brophy, 2004; Davis & Falba, 2002). Professional development to support this vision must also be an active and dynamic process. Such professional development needs to reflect the same constructivist pedagogical delivery

Of key importance to the goal of fostering the implementation of open-ended inquiry in science is the need for a professional development program that reduces teacher confusion (Wee et al., 2007) around what open-ended inquiry is and what it would look like in the classroom. Providing teachers with first-hand experience should serve to remove some of this reported confusion. Additionally, research indicates that such professional development should be a long-term initiative incorporating the building of communities of practice and opportunities for extended reflection (Anderson, 2002; Blumenfeld, Krajcik, Marx, & Soloway, 1994; Krajcik et al., 1994; Melville & Bartley, 2010; Singer, Marx & Krajcik, 1992; Van den Berg, 2002). Blumenfeld et al. (1994) identified the need for teachers to have time to reflect in order to determine what would work best with their own students in their own school context.

Anderson (2002) advises that: “Collaboration is a powerful stimulus for the reflection which is fundamental to changing beliefs, values, and understandings” (p. 9). A professional development model to support enactment of open-ended inquiry which includes collaboration during cycles of planning, enactment, and reflection is described by Krajcik et al. (1994). Their model builds in long-term support for teachers as they enact open-ended inquiry, building expertise and discovering ways to resolve difficulties as they emerge during enactment.

The National Research Council (2000) advises that “it can take a significant amount of time to make transformational changes in teaching” (p. 91) such as those required to support the implementation of open-ended inquiry. This position is supported in the literature where long-term,
in-service programs are recommended that employ a variety of instructional strategies (Kimble, Yager, & Yager, 2006; Lederman, 2004; Melville & Bartley, 2010; Penick & Yager, 1983). Loucks-Horsley and Matsumoto (2003) confirm that provision needs to be made to support teachers’ learning on a long-term basis, identifying ongoing teacher learning with feedback as being key to changing teacher practice including linking new conceptions of instructional practice with assessment of students learning. When implementing an innovation, Van den Berg (2002) cautions that teachers, with intensive support, begin to demonstrate higher levels of self-efficacy after two years. Additionally, he indicates that the amount of professional growth attained by teachers depends on their interpretation of their experiences and the expectations and demands placed on them as professionals.

Davis and Falba (2002) advise that open-ended inquiry in science puts into place a very different vision of science education, shifting our focus from the view of a transmitted curriculum to the view of a ‘lived’ curriculum; one that incorporates students’ interests, needs, and the voices of teachers and students as members of communities of learning. To successfully enact open-ended inquiry, teachers need to become skilled in new “ways of talking, thinking, and interacting with science content, its practices and technology (Davis & Falba, 2002, p. 323). As such, teachers’ professional development must emphasize pedagogical knowledge and pedagogical content knowledge rather than content knowledge (Kimble, Yager, & Yager, 2006) and be grounded in the classroom (Melville & Wallace, 2007). Anderson (2002) advises that enacting open-ended inquiry is a complex process and maintains that successful in-service professional development will be no less complex.

The need for reform of teacher professional development to support the enactment of open-ended inquiry is recognized in research (Kimble, Yager, & Yager, 2006; Lotter, Harwood, &
Bonner, 2006; Yager, 2005). Lotter, Harwood, and Bonner (2006) argue that an effective strategy for professional development is to engage teachers in identifying key issues related to their own professional development. Yerrick, Parke, and Nugent (1997) agree and call for future research in areas of science teachers’ beliefs in support of identifying appropriate professional development strategies to support the enactment of open-ended inquiry in real classrooms. My study responds to this call.

In summary, research indicates that a long-standing call for the enactment of open-ended inquiry in science has not been realized. Although this type of science is reported as being difficult for teachers to implement, research also confirms that teachers can teach open-ended inquiry. Researchers argue that open-ended inquiry in science will not be widely adopted unless factors that serve as significant challenges to teachers’ enactment of open-ended inquiry in science are identified and specific types of meaningful program support for the implementation of open-ended inquiry are established. The main goal of this study is to identify factors that affect the implementation of open-ended inquiry and contribute to reducing this gap between the vision of science found in curriculum documents and teachers’ practice related to enactment of open-ended inquiry in science at the secondary school level.

The theoretical grounding for this study is related to teachers’ views about teaching and learning in inquiry. Teachers’ views are considered to be derived from the interplay of clusters of teachers’ beliefs and knowledge. The position adopted in this study is in accordance with the literature, that teachers’ beliefs are the basis of action, influencing their decisions and judgments and serving as a filter for new information. Associated with this position is the view that teachers’ previous experiences and teachers’ personal practical knowledge influence the processing of new information. Personal practical knowledge is considered to be context-specific, school-based
knowledge accumulated through teachers’ classroom-based practice including past and present experiences and future plans that could impact teaching practice.

In chapter 3, I present the rationale and design of this study. In addition, I describe the methodology and methods used to generate and interpret the data with which to answer the four research questions that guide this study. Additionally, I describe the process of gaining ethical approval and the process of selecting participants.
CHAPTER 3
METHODOLOGY

This chapter describes the methodology and research methods used to carry out this study. I also present the rationale for my choice of methodology and my study design; describe the participants of this study; data collection, and interpretation; and outline the process of obtaining ethical approval.

The following research questions guided this study:

1. What beliefs do science teachers report that relate to teaching and learning in inquiry as practical work in science?

2. What types of inquiry do science teachers report enacting in secondary school science?

3. Which factors are reported to represent challenges to the enactment of open-ended inquiry as practical work in science at the secondary school level?

4. According to teachers, what types of program support would facilitate the enactment of open-ended inquiry as practical work in science at the secondary school level?

Rationale and Study Design

A mixed methods research design (Jang, 2008; Johnson & Turner, 2003) is used to explore the four research questions in this study. My decision to conduct a mixed methods study is based on the research position that both quantitative methods, providing breadth of perception, and qualitative methods, providing depth of perception, are needed to more fully understand the phenomenon under study (the enactment of inquiry in science) (Tashakkorii & Teddlie, 1998). In addition, I adopt a research position that is both flexible and adaptive (Reichardt & Cook, 1979), reflecting a pragmatic
stance with the goal of mixing qualitative and quantitative methods to achieve “what will work best” (Greene & Caracelli, 1997) in this specific context to answer the research questions that drive this study.

Believing that human behavior is intentioned (Howe, 1992), my choice of a mixed methods approach is based on the research goal of striving for knowledge claims that are grounded in the complex, contextual ‘real life’ experiences and decision-making of the participants, thereby, reflecting depth and contextual relevance. An additional research goal of this study is to capture breadth and representativeness of perspective for the pool of secondary school science teachers targeted for this study (Greene & Caracelli, 1997).

In addition to inter-method mixing (Johnson & Turner, 2003) with quantitative data being collected in Stage 1 and qualitative data being collected in Stages 1, 2 and 3, this mixed method study also has a multi-method (Brewer & Hunter, 2006) element which includes intra-method mixing in stage one. Johnson and Turner (2003) describe intra-method mixing as “concurrent or sequential use of a single method that includes both qualitative and quantitative components” (p. 298). Intra-method mixing is used in the Stage 1 questionnaire where quantitative data (closed-ended questions) and qualitative data (open-ended questions) are collected concurrently (Greene, Caracelli, & Graham, 1989) or simultaneously (Tashakkori & Teddlie, 1998).

Additionally, this study incorporates a triangulation design (Creswell & Plano Clark, 2007). Describing triangulation design as the most common approach to mixing methods, Creswell and Plano Clark (2007) identify the purpose of triangulation design as: “obtaining different but complementary data on the same topic” (p. 62). In this study, a convergence model of triangulation design is adopted with the results of qualitative analysis being used to confirm and expand the results
of quantitative data (Creswell & Plano Clark, 2007), through direct comparison, during interpretation.

Data collection and analysis (quantitative and qualitative) occurred, in this study, during three stages including a questionnaire (quantitative + qualitative) in Stage 1 followed sequentially by a short (5-10 min.) semi-structured interview (qualitative) in Stage 2, and an in-depth (30-60 minute), semi-structured interview (qualitative) in Stage 3. The findings in Stage 1 were used to identify topics and issues to be examined in greater detail in Stage 3 and, additionally, to identify a pool of self-selected volunteers for participation in Stage 3. Stage 2 was used to purposely select a sample of participants for Stage 3 based on a priori criteria that emerged from the findings in Stage 1. These Stage 3 participants were drawn as a subsample of Stage 1 participants who had signed, during Stage 1, to confirm their willingness to participate in the Stage 3 interview (see Figure 1 for the research design). Bazeley (2003) advises that the decision to use quantitative data collection to support participant selection for qualitative interviews yields the secondary benefit of potential for comparing the data from the smaller sample (the Stage 3 in-depth interview) with data from the larger and more representative sample of the population under study (the Stage 1 questionnaire).
Figure 1. A 3-stage mixed methods design.

Participants

Stage 1

A sample of 83 science teachers (42 females and 41 males) from a population of 104 teachers who represented all of the secondary school science teachers currently employed by Pine Valley District Public School Board self-selected as participants in Stage 1 (see Appendix F for teachers’ demographic information). Pine Valley is a medium-sized, district public school board in the researcher’s home region. A largely homogeneous student body of seventeen thousand urban and rural students attends the 16 secondary schools supervised by the board of education.

Each of the 104 science teachers was invited to participate in this study (see Appendix C.2 for letter of introduction). Eighty percent of these teachers responded by completing the Stage 1
questionnaire containing open-ended and closed-ended questions. During Stage 1, all respondents to the questionnaire were invited to participate in Stage 3. Of the 83 science teachers who submitted a completed questionnaire, 32 participants (39 percent of Stage 1 participants) signed to volunteer as participants for Stage 3.

Stage 2

In Stage 2, qualitative data was collected during a short semi-structured interview (5-10 minutes) with each of the 32 Stage 1 participants who had signed to volunteer (see Appendix E1 for interview protocol) for participation in Stage 3. Selection of a subsample of participants for the Stage 3, in-depth interview was based on a priori criteria (see below) that emerged in the Stage 1 findings.

Purposeful selection of this sample of Stage 3 participants was based on the following criteria developed following quantitative data analysis and incorporating emergent themes: (a) a balance in gender; (b) a range of qualifications in science; (c) a range of teaching experience in science; (d) a range of teaching practices related to inquiry as practical science. The overall goal during this participant selection process was to select a broad range of teachers in terms of teaching experience and teaching practices related to inquiry.

Creswell (2002) identifies purposeful sampling as an approach whereby a researcher selects individuals for study who are judged to be ‘information rich’ in terms of the phenomenon being studied. The science teachers selected for participation in Stage 3 were judged to be information rich in terms of their teaching experience in general and teaching experiences related to inquiry in science.
Stage 3

Applying the criteria identified above (p. 39) for the selection of Stage 3 participants, 17 secondary school science teachers (representing 20 percent of the Stage 1 participants) were selected. This sample of participants included: (a) 9 female and 8 male science teachers; (b) 4 heads of science and 13 classroom teachers; (c) 4 physics teachers, 7 chemistry teachers, 7 biology teachers; (d) 4 teachers with less than 10 years of teaching experience; 8 teachers with 10-20 years of experience; and 5 teachers with more than 20 years of teaching experience; (f) 12 teachers who reported and described teaching open-ended types of inquiry and 5 teachers who reported and described teaching confirmation and structured inquiry (closed-ended types of inquiry) but not open-ended types of inquiry. See Appendix F.2 for Stage 3 participants’ demographic information.

Data Collection

Stage 1

In Stage 1, a questionnaire was used to collect quantitative and qualitative data from 83 participants (representing 80% of the target population) pertaining to their beliefs about teaching and learning related to inquiry; challenges to the enactment of open-ended inquiry; and recommendations for program support. Quantitative data was collected as participant response to each of 37 closed items in the Stage 1 questionnaire. Each item measured the strength of teachers’ agreement on a 6-point Likert-type scale (1 = strongly disagree; 6 = strongly agree). These questions were designed to measure teachers’ reported beliefs about teaching and learning that relate to inquiry. Additionally, qualitative data was collected as participant response to open-ended questions about challenges to and program support for the implementation of inquiry in science.
The Teachers’ Reported Beliefs measure was developed with an a priori assumption, supported by the literature (Abd-El-Khalick et al., 2004; Anderson, 1982; Anderson, 2002; Banilower, Heck & Weiss, 2007; Bell et al., 2003; Chin & Chia, 2004; Cronin-Jones, 1991; Eick & Reid, 2002; Entwistle & Walker, 2002; Garet, Porter, Desimone, Birman & Yoon, 2001; Hativa & Goodyear, 2002; Hativa, 2002; Hogan & Berowitz, 2000; Keys & Kennedy, 1999; Southerland, Gess-Newsome & Johnston, 2003; Stipek, Givven, Salmon & MacGyners, 2001; Tafoya, Sunal & Knecht, 1980; Yager, 2005) that teachers’ beliefs about teaching and learning related to inquiry would be dichotomous with a knowledge transmission view or orientation at one pole and a learning-facilitation view or orientation at the opposite pole.

As reported in chapter 2, teachers holding a knowledge-transmission orientation of inquiry were expected to be teacher-focused and content-centred with a teaching emphasis on covering the content in the curriculum. It was expected that they would teach confirmation inquiry as objective data gathering in ‘recipe’ textbook labs where student would be expected to follow specific instructions carefully and accurately to verify previously learned scientific information accessible in the textbook. These teachers, as also reported in the literature, were expected to view their teaching role as transmitting scientific knowledge as a static collection of proven facts, which students would memorize in rote fashion. Academic success would be recognized as precise and rapid acquisition of knowledge coupled with accurate and rapid answers to questions present by the teacher in class, in textbook or during tests and exams. With marks viewed as the drivers of teaching and learning, students’ mastery of scientific knowledge was expected to be associated with their students’ potential for future academic success in science. The textbook would be viewed as central to teaching and learning in the classroom of these teachers and, lastly, a high value would be placed on being in control of students’ learning and behavior (Entwistle & Walker, 2002; Roth &
In contrast, teachers holding a learning-facilitation view or orientation were expected to be student-oriented considering learning as being individualistic and emergent (Dewey, 1910). These teachers were expected to place teaching emphasis on facilitating student learning and development in a classroom which is student-centred, democratic and collaborative. Student independence in learning would be valued and student-directed types of inquiry would be enacted. Teachers holding this view were also expected to emphasize making science relevant for students by connecting their learning to real-life experiences and real-life events and issues outside of the classroom (Abd-El-Khalick et al., 2004; Crawford, 2007; Entwistle & Walker, 2002; Gow & Kember, 1993; Stipek et al., 2001).

Qualitative data, collected in Stage 1, took the form of participant responses to open-ended questions designed to identify: (a) challenges to the enactment of open-ended inquiry in science; and (b) types of program support that would foster the enactment of open-ended inquiry.

**Stage 2**

In Stage 2, qualitative data was collected as researcher’s written notes during a short (5-10 minute) semi-structured interview to support participant selection for Stage 3 of this study. Participants (32), who had signed as a volunteer (self-selection) during Stage 1 for participation in Stage 3, were interviewed. The interview protocol developed (see Appendix E.1) was designed to support selection of a sample of Stage 3 participants representing a broad range of teaching experience and teaching practices related to inquiry.
This qualitative data (as researcher’s notes) was summarized and analyzed in support of purposeful selection of Stage 3 participants. As indicated earlier, a prior criteria developed from the Stage 1 findings were the basis for selection of the Stage 3 participants. The goal in participant selection was to give voice to a range of science teachers.

**Stage 3**

In Stage 3, qualitative data was collected as interview data. Seventeen Stage 3 participants (20 percent of the Stage 1 participants) were interviewed individually in a quiet location of their choice. The interview protocol (see Appendix E.2 for Stage 3 interview protocol), developed for this in-depth (30 to 60 minute) interview, was designed to address topics and issues that emerged during analysis of the Stage 1 survey data as well as other questions about beliefs and practices related to inquiry. The protocol contained primarily open-ended questions. These questions were designed to collect qualitative data pertaining to teachers’ beliefs about teaching and learning related to inquiry; types of inquiry enacted in secondary school science; factors representing challenges to teachers’ enactment of open-ended inquiry; and types of program support recommended to foster enactment of open-ended inquiry in science.

Probing questions and paraphrasing were also included in each interview to clarify responses to questions and to encourage teachers to re-examine aspects of topics or issues discussed.

**Quantitative Analysis**

In Stage 1, quantitative data was collected as Likert scale responses (1=strongly disagree and 6=strongly agree) to the 37 items in the Teachers’ Reported Beliefs measure. This Beliefs’ measure was developed based upon the theoretical position, supported by the literature, that two opposing
teachers’ views (a knowledge-transmission view of teaching and learning and a learning-facilitation view of teaching and learning) (Gow & Kember, 1993) influence the implementation of inquiry.

Based on the a priori assumption that the measuring instrument was bi-dimensional, 2 factors were extracted using exploratory principal components factor analysis with Varimax rotation. Green and Salkind (2008) recommend that four criteria be used to determine the number components or factors to retain in the exploratory factor analysis. These include: (a) the a priori conceptual beliefs based on past research and theory; (b) retention of only the factors or components with an eigenvalue $>1$ where an eigenvalue corresponds to the “amount of variance of the variables accounted for by a factor” (Green & Salkind, 2008, p. 317); (c) retention of components based on the Scree Test involving interpretation of a graphical plot of the eigenvalues (vertical axis) versus their ordinal number (the first eigenvalue, the second eigenvalue etc.) where all eigenvalues (and, therefore, components) in the ‘steep descent’ before the elbow of the plot, when eigenvalues start to level off, are retained; (d) retention of components or factors based on their relative interpretability in terms of the researcher’s knowledge about the component or factors and how they rationally and theoretically relate to the constructs. The scree test from the 2-factor solution showed that a 4-factor solution might be more appropriate as 4 components had eigenvalues $>1$. Therefore, a second exploratory principal components factor analysis was conducted followed by varimax rotation. This time 4 factors were rotated.

In the goal of improving the reliability of the Teachers’ Reported Beliefs measure with a factor solution that would account for more than 50 percent of the item variance, item analysis based on reliability procedure (Green & Salkind, 2008) was conducted. My intention was to revise the Beliefs measure by deleting some of the items that negatively related or that very weakly related to the other items in the measure. To support these decisions, a corrected item-total correlation (the
correlation between each item in the measure and the total scale score excluding that particular item) (Green & Salkind, 2008) was calculated for each item. In cases where a negative corrected item-total correlation was obtained, it was determined that this particular item of interest was not particularly relevant to the Teachers’ Reported Belief measure (Green & Salkind, 2008) and the item was deleted. In addition, all items with correlations less than .20 ($r < .20$) were examined for possible deletion from the measure.

In all cases, a decision to delete an item included consideration of the item content and its relationship to the total Teachers’ Reported Beliefs measure. This was supported by researcher knowledge about the items and how they rationally and theoretically related to the constructs associated with the four components extracted during principal components factor analysis. A revised Teachers’ Reported Belief measure with 22 items was produced (See Appendix D for the Revised Teachers’ Reported Beliefs Measure).

Principal components factor analysis was conducted on this revised Teachers’ Reported Beliefs measure followed by varimax rotation with four factors rotated based on the earlier scree plot analysis. Coefficient alphas, as Cronbach’s alphas, were, then, computed for each of the extracted components (factors) to confirm internal consistency of the items in each associated scale (see Table 1, p. 55). Alpha scores of .70 or higher were considered to indicate a high level of internal reliability (Vogt, 2005). Each scale was, then, examined for interpretability.

Item analysis was, next, performed using reliability procedure, to confirm that the individual items in each scale were correlated with their own scale (convergent validity) and that each item in a scale was more highly correlated with its own scale than with items associated with the other three scales (discriminant validity) identified in this revised Teachers’ Reported Beliefs measure (Green & Salkind, 2008) (see Table 2, p. 59). Convergent validity for each scale was tested by computing
correlations between item scores for a scale and a corrected total scale score (the total scale score excluding that particular item). To determine discriminant validity, the item scores for a scale were correlated with the total scale scores for the other three scales (dimensions) identified in this study (Green & Salkind, 2008).

To examine the relationship between each pair of scales, correlation coefficients were computed and a correlation matrix was constructed (see Table 3, p. 60). Lastly, K-means analysis was conducted to determine if the total group of participants would partition into subgroups (Lattin, Carroll, & Green, 2003).

**Qualitative Analysis and Interpretation**

Constant comparison analysis or a grounded theory approach (Creswell, 2002) was used to analyze all qualitative data. Constant comparative analysis is an inductive approach to data analysis which involves carefully examining the data for emerging themes then collapsing these themes into larger and larger themes. This was done by first carefully reading the qualitative data (fully transcribed audio-taped interview data and survey data as responses to open-ended questions) and then coding and categorizing the incidents of data. At that point, categories of data were compared with other categories of data followed by the progressive collapsing of smaller categories into larger and larger categories to generate a list of first, smaller (minor) themes and then, larger (major) themes. The intent during this process was to ‘ground’ themes (major and minor) in the data.

Qualitative data analysis took place in two phases. In the first phase, qualitative interview data pertaining to teachers’ reported beliefs about teaching and learning in relation to inquiry (research questions 1 and 2) were analyzed thematically using constant comparison analysis. Qualitative Stage 3 findings were then merged with quantitative Stage 1 findings during
interpretation with qualitative results being used to confirm and expand quantitative results through direct comparison. This approach provided a broader and more representative picture of teachers’ beliefs and teaching practices pertaining to the enactment of open-ended inquiry.

In the second phase, qualitative survey data (as responses to open-ended questions) and interview data pertaining to challenges and program support to foster open-ended inquiry in science (research questions 3 and 4) were analyzed. First, qualitative Stage 1 survey data (responses to open-ended questions) were analyzed thematically and quantized. Next, the Stage 3 transcribed interview data related were analyzed thematically and quantized. These two sets of quantitative results (quantized survey and interview results) were then merged with qualitative results (qualitative survey and interview results) during interpretation with qualitative results being used to confirm and expand quantitative results. This approach provided a more fine-grained view of both the challenges experienced by these teachers in relation to enactment of open-ended inquiry and the types of program support recommended by them to foster teachers’ implementation of open-ended inquiry.

**Trustworthiness**

Several strategies were used in this mixed methods study to increase trustworthiness (Lincoln and Guba, 1985) in the findings.

Credibility and confirmability of these findings were increased through use of the following strategies:

- The purposeful selection of a subsample of stage 1 science teachers for participation in the stage 3 in-depth interview to support triangulation of data.
Data reduction and analysis in two stages with quantitative analysis preceding qualitative analysis. Additionally, quantitative findings informed qualitative data collection and analysis in Stage 3.

The use of stage 3 qualitative interview findings to confirm and expand the quantitative survey findings from stage 1. This approach to triangulation of data linked and added strength to the findings expanding the different aspects of topics and issues pertaining to the enactment of open-ended inquiry.

The use of probing questions during stage 3 data collection to clarify answers. Additionally, answers were paraphrased back to the participants at points during this interview to provide assurance that I was correctly interpreting their answers.

The use of constant comparison analysis to ground the findings in the data. In doing so, a concerted effort was made to accurately and fully represent topics and issues relating to enactment of open-ended inquiry in secondary school science.

Consideration of alternative interpretations during constant comparison analysis.

Statistical analysis of survey data confirmed validity and reliability in quantitative findings.

The dependability of these findings was increased by:

Purposefully selecting selection of a subsample of stage 1 teachers as participants for the stage 3 in-depth interview.
Controlling researcher bias by maintaining research distance (neutrality) during qualitative data collection and analysis. Additionally, practical matters did not influence either data collection or analysis. It should also be noted that my own influence does need to be considered. I am a former secondary school science teacher, head of science, and curriculum leader with this board who was known to several of the Stage 3 participants interviewed. However, I do not think that this relationship contributed to researcher bias rather that the connection established by our common experience of time spent teaching science contributed instead to a willingness of teachers to respond honestly and fully to the questions asked.

Maintaining objectivity throughout data collection and analysis. Additionally, the information being reported was clarified through use of both probing questions and paraphrasing.

Collapsing a category of information as negative and conflicting data emerged.

Rigorously collecting data throughout this study with a survey response rate of 80% of the target population of secondary school science teachers and the purposeful selection of a subsample of 20% of stage 1 participants for the stage 3 in-depth interview. A limitation is noted in that only one population of science teachers was studied.

Transferability of findings to other settings may be possible as a result of:

The collection of both quantitative and qualitative data. While quantitative data was collected to add breadth and representativeness to the findings of this study,
qualitative data was collected to add depth and contextual relevance to the findings. Together, these two types of data combined to increase the accuracy in the findings.

- A response rate of 80 percent of the target population in stage 1 and the purposeful selection of a subsample of stage 1 science teachers for participation in stage 3. As previously indicated, a subsample of 17 teachers (representing 20% of stage 1 participants) was selected for the in-depth interview in stage 3.

- Thickness in the descriptions of teachers’ reports of major and minor themes that emerged in the data. These descriptions should provide sufficient information for readers to establish a degree of similarity and therefore establish some degree of transferability to other settings.

- Merging of quantitative findings (representing 80% of the target population) with the qualitative findings (representing 17% of the target population) during interpretation to triangulate quantitative results and, thereby, add strength to the generalizability of the findings of this study (Johnson & Turner, 2003).

However, Lincoln and Guba (1985) remind readers that it is not the job of naturalistic researchers to provide an index of transferability to findings.

In chapter 4, I discuss the process of revising the Teachers’ Reported Beliefs measure and discuss the development of a tentative framework containing four quadrants to illustrate the dimensionality of teachers’ beliefs and teaching practices related to inquiry. A set of beliefs profiles is developed to correspond to each of the four dimensions in my framework.

I, next, describe the categorization and characterization of four types of Stage 3 teachers differentiated by their reported preferred practices in teaching inquiry and describe the development
of a set of beliefs profiles corresponding to the teachers’ reported beliefs and practices related to inquiry in science. A stance is identified to correspond with each belief profile. The two sets of beliefs profiles (quantitative and qualitative) are, then, compared and merged to form one composite set of beliefs profiles to correspond to the quadrants in my tentative framework. Lastly, I expand my framework to incorporate the composite set of beliefs profiles.
Developing a Tentative Framework

In this chapter, I discuss data analysis and the process of developing a framework to illustrate the dimensionality of teachers’ beliefs and teaching practices related to inquiry. Challenges and recommended program support for open-ended inquiry will be discussed in succeeding chapters.

Here, I begin discussion of data analysis pertaining to teachers’ beliefs and practices with a summary of the process which was followed in analyzing Stage 1 data. This quantitative data analysis resulted in development of a revised Teachers’ Reported Beliefs measure and a tentative framework to illustrate the dimensionality of teachers’ beliefs about teaching and learning related to inquiry. Next, I summarize the results of thematic analysis of Stage 3 interview data pertaining to the first two research questions (What beliefs do science teachers report that relate to teaching and learning in inquiry as practical work in science? and What types of inquiry do science teachers report enacting in secondary school science?). Lastly, I integrate both quantitative and qualitative results and conclude with an expanded framework illustrating the dimensionality of teachers’ beliefs and teaching practices related to inquiry in science.

Initial exploratory factor analysis with rotation of 2 factors (varimax rotation procedure) resulted in only 20 percent of the item variance being accounted for, with two indecipherable factors being identified. The scree plot showed that a 4-factor solution would be more appropriate (4 factors with eigenvalues >1). Therefore, a second exploratory principal components factor analysis was conducted followed by varimax rotation. This time 4 factors
were rotated. The results indicated that 40 percent of the item variance was accounted for and four factors were identified that could be deciphered. In the goal of attaining a factor solution that would account for more than 50 percent of the variance, it was determined that revision of the Teachers’ Reported Beliefs measure should be undertaken.

Item analysis, conducted on the 37 items of the Teachers’ Reported Beliefs measure, revealed that 7 items had a negative corrected item-total correlation and that 16 items had correlations less than .2 ($r < .20$). Each of these items was examined for possible deletion from the measure (see Appendix F.3). Based on item analysis and determination of the importance of the item to the Beliefs measure as a whole and to its own scale, a total of 15 items were deleted to create a 22-item, revised Teachers’ Reported Beliefs measure.

Principal components factor analysis was conducted on the revised Teachers’ Reported Beliefs measure. As indicated by earlier scree plot analysis, four factors were rotated using varimax rotation procedure. This time collectively, before rotation, these four factors accounted for 54.0 percent of the item variance and the rotated solution yielded four interpretable components (factors) that accounted for 22.3 percent, 15 percent, 9.5 percent, and 7.3 percent of the item variance respectively before rotation.

Teachers’ beliefs profiles were developed for each component (factor) using the items associated with that particular scale. Based on the content of these four profiles, four constructs (one associated with each component) were identified including: an open-ended view of inquiry; a closed-ended view of inquiry; a teacher-directed view of learning; and a student-directed view of learning. Alpha scores for each of the four teachers’ beliefs scales (components) were calculated as .812, .702, .709, and .702 respectively indicating a high level of coherence within the items for each scale (see Table 1, p. 55).
Table 1

*Reliability Estimates of Four Composite Scales*

<table>
<thead>
<tr>
<th>Component #</th>
<th>Construct</th>
<th>Alpha</th>
<th># items (N = 83)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Teacher-Directed View of Learning (TDL)</td>
<td>.812</td>
<td>7</td>
</tr>
<tr>
<td>2</td>
<td>Open-Ended View of Inquiry (OEI)</td>
<td>.702</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>Student-Directed View of Learning (SDL)</td>
<td>.709</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>Closed-Ended View of Inquiry (CEI)</td>
<td>.702</td>
<td>3</td>
</tr>
</tbody>
</table>

Based on the results of factor analysis and reliability analysis, total scores for each of the 4 scales were computed by running up the scores from individual items. A correlation matrix was constructed to examine the relationship between each pair of scales scores measuring the four identified constructs (see Table 3, p. 60). From this matrix, a highly tentative framework was developed to illustrate the dimensionality of teachers’ reported beliefs about teaching and learning related to inquiry as practical science. This framework consists of two intersecting axes (see Figure 2, p. 57). A closed-ended view of inquiry and an open-ended view of inquiry (which negatively correlate) represent opposite poles along the vertical axis with a student-directed view of learning and a teacher-directed view of learning (which negatively correlate) representing opposite poles along the horizontal axis. Four quadrants are created in this framework which could represent four different types of teachers differentiated on the basis of their beliefs and teaching practices related to inquiry as practical science. Teachers’ belief profiles developed from the scale items associated with each extracted component of the revised Teachers’ Reported Beliefs measure were incorporated into the framework (see Figure 3, p. 58).
Convergent and discriminant validity were confirmed for the revised Teachers’ Reported Beliefs measure. As shown in Table 2 (see p. 59), correlation scores indicated that, in every case, each item in a scale measuring an identified construct (component) was correlated with each of the other items in its own scale (convergent validity). Furthermore, each item in a scale was more highly correlated with its own scale than with any of the other 3 scales identified (discriminant validity) in the measure. Lastly, K-means clustering of the 83 participants stabilized after 6 iterations with the identification of 4 clusters (subgroups) of participants (containing 38, 24, 16, and 5 participants respectively) based on the patterns in their responses to items in the revised Teachers’ Reported Beliefs measure. An ANOVA indicated significant main effects for each of the four scales on classification of participants into 4 clusters ($p < .01$) (see Table 3, p. 60).
Figure 2. The dimensionality of science teachers’ reported beliefs about teaching and learning that relate to inquiry as practical work in science.
**Open-Ended Inquiry (OEI)**

- Teacher as facilitator
- Scientific practices similar to those of real scientists
- Student independence in investigations
- Student independence in investigating problems posed by others (guided inquiry)
- Student-directed independent investigation in topic area of interest (fully open inquiry)
- Students following ‘recipe’ labs do not achieve the most effective learning
- Scientific knowledge is tentative, not fixed

**Student-Directed Learning (SDL)**

- Science instruction should relate to students’ interests
- Science instruction should relate to real-life events and issues
- Students can be creative
- Student collaboration is important to learning
- Evaluation includes student improvement

**Teacher-Directed Learning (TDL)**

- Teacher confidence in training
- Teacher confidence in mastery of scientific knowledge
- Mastery of knowledge (content and basic skills) as preparation for the future education in science
- Teacher control of learning (content & skills)
- Answering questions quickly as evidence of academic capability
- Correct answers to questions as evidence of learning in science
- Marks as motivators

**Closed-Ended Inquiry (CEI)**

- Emphasis on careful and precise thinking
- Science investigations as ‘recipe’ labs for verification of previously learned scientific principles (confirmation inquiry)
- Student investigations as ‘learning by discovery’ (structured inquiry)

*Figure 3.*Teachers’ beliefs profiles pertaining to teaching and learning and inquiry by dimension.
## Table 2

**Correlations Between Teacher Belief Items and Belief Factors**

<table>
<thead>
<tr>
<th>Teacher belief items</th>
<th>TDL</th>
<th>OEI</th>
<th>SDL</th>
<th>CEI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Teacher-Directed View of Learning (TDL) items</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher confidence in training</td>
<td>.65</td>
<td>-.21</td>
<td>-0.01</td>
<td>.13</td>
</tr>
<tr>
<td>Teacher confidence in mastery of scientific knowledge</td>
<td>.76</td>
<td>-.15</td>
<td>-.04</td>
<td>.03</td>
</tr>
<tr>
<td>Mastery of scientific knowledge as preparation for future education in science</td>
<td>.67</td>
<td>.09</td>
<td>-.10</td>
<td>.16</td>
</tr>
<tr>
<td>Teacher control of student learning (content and skills)</td>
<td>.58</td>
<td>.26</td>
<td>-.10</td>
<td>.30</td>
</tr>
<tr>
<td>Answering questions quickly as evidence of academic capability</td>
<td>.75</td>
<td>.05</td>
<td>-.13</td>
<td>.15</td>
</tr>
<tr>
<td>Correct answers to questions as evidence of learning in science</td>
<td>.64</td>
<td>.39</td>
<td>-.04</td>
<td>.06</td>
</tr>
<tr>
<td>Marks as motivators</td>
<td>.65</td>
<td>.35</td>
<td>-.06</td>
<td>.11</td>
</tr>
<tr>
<td><strong>Closed-Ended View of Inquiry (CEI) items</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emphasis on careful and precise thought</td>
<td>.22</td>
<td>-.09</td>
<td>-.14</td>
<td>.71</td>
</tr>
<tr>
<td>Student investigations as ‘recipe’ labs for verification of previously learned principles (confirmation inquiry)</td>
<td>.07</td>
<td>.12</td>
<td>.08</td>
<td>.82</td>
</tr>
<tr>
<td>Student investigations as ‘learning by discovery’ (structured inquiry)</td>
<td>.15</td>
<td>.12</td>
<td>.35</td>
<td>.68</td>
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<tr>
<td><strong>Open-Ended View of Inquiry (OEI) items</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teacher as facilitator</td>
<td>.21</td>
<td>.64</td>
<td>.05</td>
<td>.05</td>
</tr>
<tr>
<td>Scientific practices similar to those of real scientists</td>
<td>.05</td>
<td>.52</td>
<td>-.18</td>
<td>.47</td>
</tr>
<tr>
<td>Student independence in investigations</td>
<td>.34</td>
<td>.61</td>
<td>.10</td>
<td>.07</td>
</tr>
<tr>
<td>Students’ independence in investigating problems posed by others (guided inquiry)</td>
<td>-.20</td>
<td>.70</td>
<td>-.22</td>
<td>.05</td>
</tr>
<tr>
<td>Student-directed independent investigation in a topic area of interest (fully open inquiry)</td>
<td>-.29</td>
<td>.61</td>
<td>-.22</td>
<td>-.04</td>
</tr>
<tr>
<td>Students following ‘recipe’ labs do not achieve the most effective learning</td>
<td>.27</td>
<td>.48</td>
<td>-.12</td>
<td>.40</td>
</tr>
<tr>
<td>Scientific knowledge is tentative not fixed</td>
<td>.35</td>
<td>.45</td>
<td>-.27</td>
<td>.03</td>
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</table>
Teacher belief items

### Student-Directed View of Learning (SDL) items

<table>
<thead>
<tr>
<th>Belief orientation</th>
<th>TDL</th>
<th>OEI</th>
<th>SDL</th>
<th>CEI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Science instruction should relate to students’ interests</td>
<td>.00</td>
<td>.00</td>
<td><strong>.82</strong></td>
<td>.07</td>
</tr>
<tr>
<td>Science instruction should relate to real-life events and issues</td>
<td>.03</td>
<td>-.27</td>
<td><strong>.49</strong></td>
<td>.23</td>
</tr>
<tr>
<td>Students can be creative</td>
<td>-.33</td>
<td>.03</td>
<td><strong>.65</strong></td>
<td>-.15</td>
</tr>
<tr>
<td>Student collaboration is important to learning</td>
<td>-.01</td>
<td>-.33</td>
<td><strong>.56</strong></td>
<td>.04</td>
</tr>
<tr>
<td>Evaluation includes student improvement</td>
<td>-.10</td>
<td>-.03</td>
<td><strong>.82</strong></td>
<td>.05</td>
</tr>
</tbody>
</table>

Table 3

**Correlations Among Summed Scale Scores for Teachers’ Reported Belief Orientations (n=83)**

<table>
<thead>
<tr>
<th>Belief orientations</th>
<th>TDL</th>
<th>OEI</th>
<th>SDL</th>
<th>CEI</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OEI</td>
<td>-.329**</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SDL</td>
<td>-.173</td>
<td>.272*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CEI</td>
<td>.287</td>
<td>-.51</td>
<td>.162</td>
<td></td>
</tr>
</tbody>
</table>

*Note. * p < .05; ** p < .01

For the purposes of this study, a closed-ended view of teaching inquiry in science is being interpreted as a traditional approach to teaching. In confirmation and structured inquiry, the students provide no input to the topic under study, the problem being investigated, the procedure being followed or the analysis of data that is undertaken. They are expected to follow, in sequence, a set of specific instructions (as a recipe) usually provided in a textbook or lab manual to either confirm previous learning or acquire new learning previously determined by the teacher and easily available to students, most often, in their textbook. In contrast, an open-ended
approach to inquiry in science is being interpreted as a type of inquiry that incorporates the five essential features of classroom inquiry identified by the National Research Council (2000, p. 25). As discussed earlier (see p. 11), these five essential features include students engaging a scientific question posed by them or provided to them (by their teacher, the textbook etc.); analyzing data to formulate an explanation to answer the scientifically-oriented question; evaluating their explanation in light of alternative explanations; and communicating and justifying their proposed explanation.

Additionally, a teacher-directed view of learning is being interpreted as a teacher-centred delivery of knowledge emphasizing teacher control of student learning. In contrast, a student-directed view of learning is being viewed as student-centred with an emphasis on teacher facilitation of student understanding in learning and incorporation of student interests and real-life applications to learning.

Lock (1990) presents a theoretical framework that is very similar to the tentative framework developed here. He indicates that his framework represents the interaction between teaching style and the open-endedness of practical work in science. I reviewed this framework after I had analyzed my quantitative data. There are strong similarities between this framework and my tentative framework. Lock describes his framework as having “two intersecting axes, one representing the continuum between closed-ended and open-ended work and the other the continuum between a teacher-directed and a student-centred approach” (p. 64). The four quadrants in his theoretical framework represent different types of practical work from the perspective of teaching style (teacher-directed vs student-centred) and the open-endedness of the work in science. My empirical framework also has two axes that intersect at right angles. One axis represents a continuum between a teacher-directed view of learning and a student-directed
view of learning. The second axis represents a continuum between a closed-ended view and an open-ended view of inquiry in science. The four quadrants created in this framework would represent four types of teachers differentiated by their beliefs and teaching practices related to inquiry in science.

Lock’s (1990) view of open-ended practical work in science incorporates each of his five criteria for identification of open-ended practical work including: students (a) defining the area of interest of study; (b) stating the problem for investigation; (c) planning the investigation; (d) determining the strategy or strategies to be used in data collection; and (e) interpreting the results of the investigation.

**Overview of Quantitative Results**

Item analysis using reliability procedures was conducted to identify items that should be removed from the 37-item Teachers’ Reported Beliefs measure. Corrected item-total correlations for each item (variable) in the measure provided the basis for deleting 15 items (variables) to create the revised 22-item Teachers’ Reported Belief measure.

Principal components factor analysis, conducted on the revised Teachers’ Reported Beliefs measure with four factors rotated (varimax rotation), resulted in 54 percent of the item variance being accounted for by the factor solution. Coefficient Alphas, calculated for the four components (factors), indicated a high level of internal consistency or coherence in the items of each scale. In addition, convergent and discriminant validity were confirmed for each scale in the revised Teachers’ Reported Beliefs measure. Four constructs were identified to represent the dimensions in the framework based on the content of scale items associated with each dimension. Additionally, a set of beliefs profiles was developed to represent the four constructs
from the scale items associated with each construct. This set of beliefs profiles was incorporated into the framework (see Figure 3, p. 58).

A correlation matrix was used to explore the dimensionality of the four scales. A tentative framework was then developed to illustrate the dimensionality of teachers’ reported beliefs about teaching and learning related to inquiry as practical science. Four quadrants are contained in this framework which would represent subgroups (types) of teachers within the total group (\( n = 83 \)) of participants (see Figure 2, p. 57). K-means analysis indicated that the total group of Stage 3 participants partitioned into four subgroups based on the patterns in their response to items in the beliefs measure.

**Characterizing Stage 3 Participants**

During the Stage 3 in-depth interview, 17 participants (representing 20 percent of the Stage 1 participants) (see Appendix Table F.2 for teachers’ demographic information) were asked to discuss their views about teaching and learning related to inquiry as practical work in science and describe their preferences in teaching inquiry (see Appendix E.2 for the interview protocol).

Thematic analysis of the interview data collected from these 17 participants indicates that there are four distinct types of science teachers differentiated by their reported beliefs about teaching and learning and preferred teaching practices related to inquiry. A stance was determined to represent each type based on the cluster of beliefs expressed collectively by all members within the group. Additionally, a general theme was identified for each stance which takes the form of a direct quote by one of the participants associated with each stance who was judged to be representative of the whole group of participants associated with that stance. Lastly,
it should be noted that membership in each type remained consistent throughout this phase of thematic analysis.

In the following section, I discuss the categorization and characterization of each of these four types of participants and present the four stances determined to represent them including: utilitarian science, content-based science, authentic contextual science and citizenship science. Lastly, I identify the general theme determined to represent each stance.

_Type 1: Utilitarian Science_

_**Teachers’ Beliefs and Teaching Practices Related to Inquiry**_

Thematic analysis of the teachers’ reported beliefs and teaching practices related to inquiry indicates that there are 4 participants (Sam, Tom, Paul, George) who demonstrate a very high level of similarity in both their reported beliefs and teaching practices. For this reason, these participants are grouped together and designated as Type 1. However, within this first group of participants, two teachers (Tom and Sam) communicate a stronger emphasis on teacher-directedness in relation to inquiry while the remaining 2 participants (Paul and George) communicate a stronger emphasis on student-directedness in relation to inquiry.

An emphasis on problem-solving emerges as the first theme in the interview data of Type 1 participants. Tom states: “I am a problem solver and I teach problem solving. I hope that I do it well.” Sam indicates that he places a high priority, in his science classes, on allowing students “to take their knowledge to the next level by providing them with opportunities to engage in those rich, diverse scientific problems.” George and Paul also report an emphasis on problem-solving where they focus on their students “doing their own (independent) investigations (as a chemistry or physics challenge) to get an appreciation of where the facts come from” (George).
These teachers indicate that guided inquiry achieves their goal of developing awareness, in students, that science is process-oriented rather than content-focused. George maintains that science education needs to “try to teach that science is not a product; it’s a process; it’s an ongoing development of knowledge; a refinement of knowledge; a process of discarding old ideas and embracing new ideas.” He emphasizes that students need to realize that “There are no definitive right answers. Everything that we know is an approximation. There is no absolute knowledge.”

The second theme that emerges in this type is an emphasis on the application of student learning, in science, to real-life situations. Sam describes his approach as “start(ing) with a theory and showing them how it works in real life.” He adds “We need people who are problem solvers not necessarily cookie cutter scientists.” Tom maintains that “I have responsibility to prepare them (students) for a very complex world and you (as a teacher) have to do that by developing their basic skills and the variety of skills that support problem solving.”

George and Paul add a more student-directed orientation reporting their belief that it is important for students, who live in a world where they can access any scientific information, to know how to critically analyze and test this information for validity and bias and, then, use this information to solve real-life problems. George states: “There is a wealth of information out there” and adds that “part of the role of the teacher is showing them (students) how to find information; vet information and filter it.” Paul adds “Science doesn’t say trust me. Science says question me. They can find the facts. We need to show kids how to question facts.” He maintains that “the facts aren’t so important if kids don’t understand where the facts come from and, by doing their own little version of the scientific process, it sort of solidifies science as something that people do.”
Teaching students to become scientifically literate citizens by mastering critical knowledge and developing problem solving skills emerges as the third theme in the interview data of the participants associated with Type 1. Sam states: “I see my role as to educate students to become scientifically literate citizens. This is accomplished in many ways. Primarily, I deliver the government-mandated curriculum and get students to extend upon that through problem-solving”. This theme is linked with a fourth theme of developing scientific literacy to prepare students for their future studies in science. Tom and Sam approach their educational goal with a stronger emphasis on teacher-directed learning. Tom states: “I do (teach) what I know students need in order to go forward to college or university.” He adds “Doing what you think is appropriate for students, is, I think, paramount to what every good teacher does.”

George, Paul and Tom communicate that they approach the educational goal of scientific literacy for both citizenship and as preparation for their future education in science. Additionally, a strongly held belief reported by George is that teachers need to teach students “how to make a case, a judgment between what you think are the valid pieces of information versus personal opinions and bias.” He adds that “The wonderful thing about science is that it is self-correcting.” Paul states: “We need change in science. I think that our job should be to teach them (students) how to live in a world where you can find all those things (facts) that you need to know by teaching them what to do with those things (facts).”

**Teachers’ Preferred Practices in Teaching Inquiry**

All of the participants in Type 1 report that they regularly enact guided inquiry as their preferred approach. For the purposes of this study, guided inquiry is being viewed as a type of open-ended inquiry that would also be classified as a type of full inquiry (National Research Council, 2000). Guided inquiry incorporates each of the five essential features of classroom
inquiry (National Research Council, p. 29) (see description on page 11). The teacher chooses the topic area and topic for study and presents the problem to be investigated. However, the procedure to be followed to solve the problem is planned and carried out by the students for the purpose of acquiring new learning (Martin-Hansen, 2002; Tafoya, Sunal, and Knecht, 1980; Windschitl, 2002).

Enactment of guided inquiry, for each of these science teachers, is reported as being usually in the area of physics or chemistry challenges. In presenting this type of problem-solving to their students, George and Paul indicate that they provide a problem to solve and the parameters of the solution but leave the determination of how (method and materials) to solve this problem to their students. Tom reports: “I give my students some limitations that they have to prioritize. I usually try to have competing principles here so that it is not a straightforward challenge.” He adds:

They really have to look at a variety of variables and try to come up with a unique answer and that’s the thing. There is no single solution. There are a variety of ways to accomplish the challenge and they have to come up with the one that suits them best.

Sam indicates that he enacts guided inquiry “where I state the problem but then, the rest is up to the student as to how to investigate and overcome the problem.” An example of a challenge provided by both of these physics teachers (Tom and Sam) would be the construction of a catapult that must be built according to certain parameters and is judged according to student success in meeting the challenge of these parameters.

Enacting confirmation inquiry (‘recipe’ labs found in textbooks) is reported by teachers associated with this stance which they use to teach and reinforce development in basic skills as preparation for application in guided inquiry. In assessing a lab report, Tom focuses on evidence
of skill development stating: “What I am looking at is how they carry out their analysis and how they do their graph; how they do their line of best fit. Can they calculate a slope properly? Do they include units properly?”

These four participants report the belief that all students should have the opportunity to do open-ended inquiry to reinforce that “science is something that you do, not something that you memorize” (Paul). George states: “Students have to understand that: science is dynamic and ever changing rather than a static collection of facts.” He adds “The kids need to understand where the facts come from.”

Although Sam and Tom report that they prefer to enact guided inquiry as opposed to fully open inquiry, Paul and George report that they are ready to begin to enact fully open inquiry now if class-based mentor support is provided. George states: “I have not gone there yet (teaching fully open inquiry) but it is somewhere that I would like to go. It is somewhere that I can see myself going. In my mind, I can see it happening. I just recognize that I am not there yet…A (class-based) mentor would be valuable.” Paul maintains that “Science classrooms need to be places where you ask questions and are given the tools to find answers or at least to find an answer. We don’t have enough of that.”

As discussed earlier, fully open inquiry is being viewed as a type of open-ended inquiry where students (singly or in groups), with their teacher serving the role of facilitator and mentor, choose a topic in an area of interest to them; pose a problem for investigation and, then, plan and carry out an investigation to answer their problem communicating their results as a written and/or oral report. Fully open inquiry offers a higher level of independence to students than guided inquiry. Both guided and fully open inquiry would be classified as types of full inquiry
incorporating each of the five essential features of classroom inquiry identified as significant by the National Research Council (2000) (See page 11).

**Summary of Type 1 Themes: Utilitarian Science**

General Theme:
“Science Needs to Focus on Critical Content and Basic Skills to Support Active Problem-Solving…Science is Something That You Do.” (Paul)

The four participants, categorized as members of Type 1 based on their reported preference in teaching guided inquiry, report beliefs that reflect a teacher-directed view of learning. However, within the whole group associated with Utilitarian Science, two participants (Tom and Sam) communicate a stronger emphasis on teacher-directed learning while two participants (Paul and George) communicate a stronger emphasis on student-directed learning. Each of these four participants, however, report that they regularly enact guided inquiry (open-ended inquiry) as their preferred approach to inquiry indicating an open-ended view of inquiry. Additionally, each science teacher associated with this stance reports teaching confirmation inquiry (textbook ‘recipe’ labs) to scaffold student skill development which is applied during guided inquiry. They do not report teaching structured inquiry. However, two of the four teachers associated with Utilitarian Science communicate that they are ready, now, to begin implementing fully open inquiry with mentor support.

The themes that emerge in the reported beliefs of Type 1 participants include an emphasis on: (a) teaching science with a problem solving focus; (b) applying student learning to real-life situations; (c) teaching students to be scientifically literate to support their future studies in science through mastery of critical knowledge (content and basic skills) and development of
problem solving skills; (d) teaching students critical content and basic skills as preparation for their future education in science (see Table 4, p. 80)

Type 2: Content-Based Science

Teachers’ Beliefs and Teaching Practices Related to Inquiry

Strong similarity in the reported beliefs and teaching practices of three participants (Sarah, Jill and Linda) indicates that these teachers could be grouped together as members of Group 2. Each of these participants reports a preference for teaching confirmation inquiry which is viewed as being a type of closed-ended inquiry based on Lock’s description of closed-ended work in science.

Thematic analysis of their interview data indicates that the goal of successfully planning and delivering the Ministry’s “mandated” (Sarah) scientific knowledge outlined in the curriculum drives their teaching practice, supported by a textbook. Sarah expresses the belief that her responsibility, as a teacher, is to follow the Ministry’s directives. She states: “I believe that the Ministry’s (mandate) is within the curriculum.” She reports that her “role is to help students grow in the aspect of the knowledge base and appreciation of this knowledge base.” Jill states that “by providing students with enough knowledge through teaching the curriculum, they will become knowledgeable citizens.”

A second theme that emerges is the reported belief that it is their responsibility to control and manage student learning including the content and basic lab skills being delivered in class. Sarah states: “I want to have control.” She adds “I want the kids to think in a controlled way.” Jill and Linda also reported concern about control and management of student learning.
Providing a safe, secure and organized environment to support student learning was the third theme that emerged in the interview data of these participants. In discussing students doing experiments, Sarah states: “You have to give them (students) specific directions so that safety doesn’t become a concern so that you get the outcome you’re looking for, or something you can discuss.” This theme linked with a fourth theme of providing students with basic skills and knowledge as preparation for the next level of education in science by meeting all of curriculum expectations.

Linda states: “I came out of teacher’s college believing that I had to teach them certain things, facts and that kind of thing. I believed that I needed to stick with the curriculum to the letter and get it all out there and prepare students for the next level.” In reflecting on her accountability as a teacher, Jill maintains “You are responsible to those (teachers) who follow you. If I don’t teach my students in Grade 9 how to solve equations, they get to Grade 10 and teachers ask if I taught them anything.” She adds “I’m in trouble, you know, that’s huge.”

**Teachers’ Preferred Practices in Teaching Inquiry**

Each teacher associated with content-based science reports a preference for teaching confirmation inquiry, a type of closed-ended inquiry in science which takes the form of ‘recipe’ or textbook labs. Confirmation inquiry represents a longstanding, traditional approach in science. With their emphasis on confirmation inquiry, these secondary school science teachers are considered as holding a closed-ended view of inquiry.

Participants report that they feel very insecure about attempting to enact open-ended types of inquiry. Linda captures the view of this group in stating:

I am a little bit nervous to try something that I’m not sure about. I might not be doing it right. It’s pretty easy to follow a set of curriculum guidelines and feel that
“you’re adhering to them appropriately. But, when it is something that is so unstructured, I would question whether I was doing it right; whether I was doing it well.

Each of these science teachers indicate readiness, with resource support, to teach structured inquiry. Linda states: “I would feel more comfortable with that (teaching structured inquiry) if I have (resource) support.”

**Summary of Type 2 Themes: Content-Based Science**

General Theme:

“Science is Something That You Know.” (Sarah)

The participants associated with content-based science communicate a teacher-directed view of learning reporting that the Ministry’s mandate for science teachers is that they should: (a) plan and deliver the scientific knowledge (topics and facts) outlined in the curriculum; (b) control and manage student learning; (c) provide a safe, secure and organized environment to support student learning; and (d) teach students the knowledge (content and basic skills) outlined in the curriculum as preparation for their next level of training in science. As a group, these science teachers report the enactment of confirmation inquiry (closed-ended inquiry) as ‘recipe’ textbook labs indicating a closed-ended view of inquiry. However, these teachers report a readiness to teach structured inquiry with resource support.

**Type 3: Authentic Contextual Science**

*Teachers’ Beliefs and Teaching Practices Related to Inquiry*

Two participants (Mark and Jeff) are grouped together to form Group 3 based on the similarities in their reported beliefs and their reported preference for teaching structured inquiry
(a closed-ended type of inquiry). These teachers report beliefs reflecting a student-directed view of learning describing their teaching role as delivering a personally, meaningful curriculum to students (all grades and levels) “taking students’ background, interests and hobbies into account” (Mark) in the planning of curriculum and classroom organization. Both George and Jeff maintain that personalizing science education for students by “connect(ing) to their (students’ interests, and backgrounds” (Jeff) should be a priority in science.

Connecting meaningfully with students in class by “organizing a classroom based on the principles of authentic discourse” (Mark) emerges as a second theme for this group of participants. Jeff states: “We need to train our students to develop logical arguments. “ In addition, he adds “We need to train our students in people skills as well as lab skills. It’s the essence of democracy. I don’t think that you can be a well-informed citizen without at least a fundamental background in scientific thinking and discourse on current (socio-scientific) issues.”

This emphasis on preparing informed citizens is also communicated by teachers associated with citizenship science, which follows as the fourth stance. However, while teachers associated with utilitarian science view this goal as being achieved through social discourse related to current socio-scientific issues, teachers associated with citizenship science view this goal as being achieved through developing a knowledge base and skill set to support critical thinking.

In doing this, Jeff maintains:

We, as teachers, need to connect with students and we have to connect students to the world-wide community of learning and learners outside the classroom.

Students want to connect with people that they respect and admire and recognize as helping them become better people. If you can present ‘the world’ of learning, kids want to learn.”
Jeff reports that he “teaches using a variety of instructional approaches, both holistic and traditional.”

Preparing students to live in a complex world by studying and logically discussing current contentious socio-scientific issues develops as a third theme in the interview data of this group of science teachers. Jeff and Mark emphasize the importance of focusing on investigating social issues related to science that can become the basis of class discussions. Jeff states: “Students want to talk about the real-life social issues. Real-life happenings not ‘cookbook’ stories.” Mark maintains that “Science needs to provide students with the opportunity to study and logically discuss contentious societal issues in science” and adds his belief that his role as a teacher is “exposing students to a variety of opinions in relation to current important socio-scientific issues using a variety of different methods.”

**Teachers’ Preferred Practices in Teaching Inquiry**

These science teachers indicate that they teach mainly confirmation (‘recipe’ or textbook labs) inquiry in their science classrooms along with some structured inquiry where students are given the problem to solve and the procedure to follow in order to learn new scientific knowledge that is pre-determined by their teacher. However, Mark and Jeff report that they prefer implementing structured inquiry in science when they have time in the curriculum. Structured inquiry is being viewed as a closed-ended type of inquiry as students are being given very little investigative freedom. Their reported preference for structured inquiry is being considered as indicating a closed-ended view of inquiry.

With regard to enacting guided inquiry, both participants indicate that teaching this type of inquiry is desirable and that they are ready to do so now but communicate that they were “not
trained in how to ‘do’ this (in teachers’ college)” (Jeff) and report that they would be confident about enacting guided inquiry if they had resource support.

**Summary of Type 3 Themes: Authentic Contextual Science**

General Theme:

“Science Needs to Connect Meaningfully to Students and Provide Scientific Knowledge That Will Prepare Them to Live in a Complex World.” (Jeff)

Science teachers categorized as Type 3 communicate a student-directed view of learning with a closed-ended view of inquiry. They report a preference for teaching structured inquiry (learning by discovery) as practical science but, often, teach confirmation inquiry (‘recipe’ textbook labs) in their science classes.

These participants report the view that, as science teachers, they strive to connect with their students by: (a) delivering a personally meaningful curriculum to students (all grades and levels) taking students’ background, interests and hobbies into account in curriculum planning and classroom organization; (b) organizing a classroom based on the principles of authentic discourse; and (c) preparing students to live in complex world through their study of and logical discussion of current real-life issues and events (socio-scientific issues).

In addition, they indicate that they are ready to teach guided inquiry, now, but would like resource support to do so.
**Type 4: Citizenship Science**

*Teachers’ Beliefs and Teaching Practices Related to Inquiry*

Eight participants are grouped together as Type 4 based on the similarity in their reported beliefs and their stated preference for enacting fully open inquiry on a regular basis in their classrooms. Four themes emerge in the interview data of these eight participants (Laura, Andrew, Nicole, Brian, Susan, Tanis, Tina, Kristen). The first theme is the reported belief that teachers are responsible for linking curriculum expectations in science meaningfully to the lives and interests of their students. These participants express the belief that this encourages students to think about how science relates to them and their everyday lives and fosters student enjoyment of science. Brian states: “They (students) have to have an appreciation of what (socio-scientific issues) is going on around them right now.” Susan reports believing that her responsibility is “opening up the concepts for the kids so they start to think about how science relates to them and their everyday lives.” Brian adds another dimension to making science meaningful for students by placing a high priority, in his science classes, on incorporating topics in which students express a high level of interest. He maintains that “If students are interested in a topic, they’ll take ownership of it; they’ll believe in what they’re doing; they’ll see the relevance of science; they’ll understand that science is not just a cookbook.”

Viewing themselves as facilitators and mentors with the role of guiding students, as independent learners, through the process of finding answers to their own questions, emerges as the second theme in the interview data of these science teachers. They also emphasize the importance of students regarding science as a process and not a product. Nicole maintains that “Students need to be able to ask their own questions and be guided in finding answers to their questions.” Kristen states: “I am accountable to the kids first and I believe my role as a science
teacher is the role of facilitator and mentor to help them (students) to get the tools to know how to find information.” For Andrew, nurturing development of the skills of inquiry in students contributes to “mak(ing) science live for students and empower(ing) and enable(ing) them to discover in science and value discovery.”

Giving students some control over the content in their science curriculum by communicating that they are free to ask questions in science and seek answers to their questions emerges as a third theme in the interview data of Type 4 participants. Andrew observes that “Kids have questions. You just have to figure out how to get them to ask a question.” These teachers communicate the belief that kids, who are empowered to learn in scientific topics of interest to them, become excited about science and the role that it plays in their lives. Laura states:

Inquiry-based science (as fully open inquiry) excites them (the students), gives them a reason to come to school; and gives them a reason to come to science class. It, also, gives a tremendous opportunity for you (the teacher) to forge a relationship with them working one-on-one with a pair of kids and discussing their topics and hearing what they have to say.

A fourth theme that emerges in the interview data of these participants is that of developing students’ scientific literacy by providing them with a knowledge base and a skill set to support critical thinking, thereby, enabling students to make and defend their own discoveries. These teachers report the belief that this type of learning serves as a fundamental basis for students, as problem-solvers and decision-makers, “to exist in a scientific world in the future even if they do not become scientists” (Susan). Nicole states: “Teachers are there to communicate what is already known about science but they also have to relate that science knowledge is changing.” She adds “We have to allow them (students) and empower them to
make and defend their own discoveries.” Of great importance to Susan is that her students, as preparation for responsible citizenship, develop the ability to “read a scientific article critically and think about whether studies have been done appropriately before they accept the information.”

**Teachers’ Preferred Practices in Teaching Inquiry**

Type 4 teachers report a preference for and regular enactment of fully open inquiry as practical science and, as such, were considered to hold an open-ended view of inquiry. As reported, in teaching this type of inquiry, their students are allowed to choose a topic and problem of interest to them for investigation. Nicole maintains that “It’s important that all students have some control over the (science) content they are learning. Choosing what they are interested in investigating does that. If they are motivated to learn, it will be in an area of interest to them.” Susan confirms that, from her experience, “Students in different grades and levels of science are all very engaged and interested in their topic.”

Nicole adds that students, who participate in fully open inquiry, “acquire a skill set that enables (them) to analyze and problem solve in other areas of science and the whole spectrum of education.” Andrew states: “It’s only through having the opportunity to do their own investigation and make their own discoveries that students begin to have a true understanding of the nature of science and scientific discovery.”
Summary of Type 4 Themes: Citizenship Science

General Theme:

“Science Needs to Connect Meaningfully to Students and Prepare Them, as Independent Problem Solvers, to Live in a Complex World.” (Nicole)

Eight participants are grouped together to form Type 4 based on the similarities in their reported beliefs and their reported preferred teaching practices related to inquiry as practical science. Each one of these science teachers communicates a strong preference for teaching open-ended inquiry with a student-directed view of learning reporting that it is the responsibility of teachers to: (a) link curriculum expectations in science meaningfully to the lives and interests of their students; (b) guide students, as facilitators and mentors, through the process of finding answers to their own questions; (c) give students some control over the content in the curriculum; (d) develop students’ scientific literacy by providing them with a knowledge base and a skill set to support critical thinking.

These teachers indicate that they regularly teach fully open inquiry in science and communicate a strong preference for the enactment of this type of inquiry in science education at the secondary school level, thereby, confirming an open-ended view of inquiry. Additionally, each of these teachers report that they teach confirmation inquiry to scaffold development of students’ investigative skills for later application during fully open inquiry.

In Table 4, I summarize the teachers’ beliefs, stances and the general theme associated with each stance.
**Table 4**

*Teachers’ Beliefs and Teaching Practices, General Themes, and Stances Related to Inquiry*

<table>
<thead>
<tr>
<th>Teachers’ beliefs</th>
<th>General theme</th>
<th>Stance</th>
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<tbody>
<tr>
<td><strong>Group 1</strong></td>
<td>* Problem-solving should be emphasized</td>
<td>Utilitarian Science</td>
</tr>
<tr>
<td></td>
<td>* Student learning should be applied to real-life situations</td>
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<td></td>
<td>* Students need to become scientifically literate through mastery of critical knowledge (content and basic skills) and development of problem-solving skills.</td>
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<tr>
<td></td>
<td>* Students need to be taught critical content and basic skills as preparation for their future science studies (university or college)</td>
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<td></td>
<td>“Science needs to focus on critical content and basic skills to support active problem-solving. Science is something that you do.” (CJ)</td>
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</tr>
<tr>
<td><strong>Group 2</strong></td>
<td>* Science content in the curriculum needs to be taught</td>
<td>Content-Based Science</td>
</tr>
<tr>
<td></td>
<td>* Teachers need to control and manage student learning</td>
<td></td>
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<td></td>
<td>* A safe, secure, and organized environment needs to be provided to support student learning</td>
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<tr>
<td></td>
<td>* Students need to be taught basic skills and knowledge in the curriculum as preparation for their next level of training in science</td>
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<td></td>
<td>“Science is something that you know.” (DM)</td>
<td></td>
</tr>
</tbody>
</table>
Teachers’ beliefs | General theme | Stance
---|---|---
Group 3
* Science curriculum needs to be personally meaningful to students (all grades and levels)
* Classroom organization needs to be based on the principles of authentic discourse
* Students need to study and logically discuss current socio-scientific issues (real-life issues and events) as preparation for life in a complex world

“Science needs to connect meaningfully with students’ and provide scientific knowledge that will prepare them to live in a complex world.” (WN)

Authentic Contextual Science

Group 4
* Curriculum expectations need to meaningfully connect to the lives and interests of students
* Students should be guided by teachers facilitating and mentoring them through the process of finding answers to their own questions
* Students need to be given some control over content in the curriculum
* Skills of scientific literacy need to be developed through a knowledge base and skill set to support critical thinking

“Science needs to connect meaningfully with students and prepare them, as independent problem-solvers, to live in a complex world.” (DC)

Citizenship Science

Expanding the Framework

A Summary of the Results of Quantitative Analysis

Quantitative analysis of the revised Teachers’ Reported Beliefs Measure resulted in four scales associated with the four components (dimensions) extracted during principal components factor analysis. Alpha scores confirmed a high level of internal consistency for each scale. Teachers’ beliefs profiles were developed for each dimension (component) using the items associated with that particular scale (see Table 2, p. 59). Based on the content of these four
profiles, four constructs (one associated with each dimension) were designated including: an open-ended view of inquiry; a closed-ended view of inquiry; a teacher-directed view of learning; and a student-directed view of learning.

A correlation matrix, used to explore the dimensionality of these four constructs (components), became the basis for the development of a tentative framework to illustrate the dimensionality of teachers’ reported beliefs about teaching and learning related to inquiry as practical science (see Figure 2, p. 57). Four quadrants are contained in this framework which would represent four groups (types) of teachers within the total group \((n = 83)\) of participants (see Figure 2, p. 57). Belief profiles (as scale items) corresponding to each dimension in the framework were then incorporated into the framework to support later characterization of participants by quadrant (see Figure 3, p. 58). K-means analysis confirmed that the total group of Stage 3 participants would partition into subgroups.

**A Summary of the Results of Qualitative Analysis**

Thematic analysis of Stage 3 interview data resulted in the identification of four types of participants differentiated by their reported preference in teaching inquiry including: guided inquiry (type 1); confirmation inquiry (type 2); structured inquiry (type 3) and fully open inquiry (type 4). Profiles of teachers’ reported beliefs and teaching practices related to inquiry were developed for each of the four types of participants. From the content of these profiles, a stance was determined. Additionally, a general theme was developed to represent each stance that took the form of a direct quote of one of the participants associated with each stance which was judged to represent the generalized view of all participants associated with that stance. These stances included: utilitarian science (type 1); content-based science (type 2); authentic contextual science (type 3); and citizenship science (type 4).
Applying the Framework

Beliefs profiles developed for the four types of participants identified during thematic analysis of interview data (see Table 4, p. 80) were examined from the perspective of the tentative framework (see Figure 3, p. 58) that resulted from the quantitative analysis of survey data. Analysis revealed that each of the four types of participants could be connected with one of the four quadrants in the framework. These connections by stance included: utilitarian science (Quadrant 1); content-based science (Quadrant 2); authentic contextual science (Quadrant 3); and citizenship science (Quadrant 4).

Teachers identified as holding a utilitarian science stance (Type 1) were associated with Quadrant 1 based on their communication of a teacher-directed view of learning (an emphasis on teaching teacher-selected, critical content and basic skills) and an open-ended view of inquiry with a reported preference in teaching guided inquiry. However, a dichotomy was found in the group of participants associated with this stance with 50% of these science teachers indicating a shift toward a more student-directed view of learning with somewhat less emphasis on controlling curriculum content and more emphasis on problem solving in real-life situations that would be meaningful to students. However, teachers reported that control with respect to the real-life situations investigated remained with them.

Type 2 participants identified as holding a content-based science stance were associated with Quadrant 2. Like Type 1 participants, they communicated a teacher-directed view of learning by emphasizing that teachers need to control and manage student learning but, unlike Type 1 participants, indicated a closed-ended view of inquiry by reporting a preference for teaching confirmation inquiry (a closed-ended approach to inquiry).
Teachers identified as representing an authentic contextual science stance (Type 3), who communicated a student-directed view of learning connected with a closed-ended view of inquiry, were associated with Quadrant 3 in the framework. This group of teachers reported an emphasis on delivering curriculum that is personally meaningful to students in a collaborative classroom environment organized based on the principles of authentic discourse about real-life issues (socio-scientific issues). In addition, both of these science teachers reported a preference for teaching structured inquiry (a closed-ended type of inquiry).

Finally, Type 4 participants, who also communicated a student-directed view of learning but combined with an open-ended view of inquiry, were associated with Quadrant 4. These science teachers reported an emphasis on connecting curriculum expectations meaningfully to the lives and interests of their students and giving students some control over the curriculum content being taught. In addition, they reported a preference for and regular enactment of fully open inquiry (an open-ended type of inquiry) as practical work in their science classes.

Comparing the Two Sets of Teachers’ Beliefs Profiles: Quantitative and Qualitative

Comparing the beliefs profiles developed for each dimension in the framework (see Figure 3, p. 58) with the beliefs profiles developed for each of the four types of participants identified during thematic analysis of interview data (see Table 4, p. 80), reveals substantial similarity. For participants considered as holding a utilitarian science stance and associated with Quadrant 1, beliefs profiles connected with two dimensions in the framework (a teacher-directed view of learning and an open-ended view of inquiry) (see Figure 3, p. 58) were compared with the Type 1 beliefs profile (utilitarian science) resulting from qualitative data analysis (see Table 4, p. 80). Only 2 items of the 13 belief items (teacher as a facilitator and marks as motivators)
associated with Quadrant 1 in the framework (see Figure 3, p. 58) were not identified during thematic analysis of the interview data of Type 1 (utilitarian science) science teachers. It is noted that, although 50% of the science teachers in this group of participants (utilitarian science) expressed a predominantly teacher-directed view of teaching and learning, there was evidence of a shifting toward a student-directed view with less emphasis on teacher control of content and more emphasis on problem solving in real-life situations that would be meaningful to students.

In the case of participants identified as holding a content-based science stance and associated with Quadrant 2 in the framework, only 1 item (answering questions quickly as evidence of academic capability) of 9 belief items in the two beliefs profiles associated with Quadrant 2 (teacher-directed learning and closed-ended inquiry) was not reported by these participants. For the two members of the authentic contextual science group (associated with Quadrant 3) only 1 item (an emphasis on logical and precise thinking) of 7 belief items in the related beliefs profiles (student-direct learning and closed-ended inquiry) was not reported by interviewees in Stage 3. However, this item was discussed indirectly. Finally, in the case of participants identified as holding a citizenship science stance, all of the belief items associated with Quadrant 4 (a student-directed view of learning and an open-ended view of inquiry) were discussed during Stage 3 interviews.

Beliefs profiles resulting from quantitative data analysis (see Figure 3, p. 58) were merged with beliefs profiles resulting from qualitative data analysis (see Table 4, p. 80) omitting 4 belief items that were not common to both sets of beliefs profiles. These consolidated beliefs profiles were then situated in framework to represent characterizations of four types of science teachers (a utilitarian science stance; a content-based science stance; an authentic contextual
science stance; and a citizenship science stance), by quadrant, from the perspective of their beliefs and teaching practices related to inquiry as practical work in science (see Figure 4, p. 87).

In chapter 5, I examine and discuss types of challenges identified as significant deterrents to the enactment of open-ended inquiry by survey respondents (Stage 1) and by interviewees (Stage 3). Qualitative data from both Stage 1 and Stage 3 are quantized and merged for comparison. I then expand on the quantitative findings (quantized survey and interview results) by applying the qualitative findings from Stage 3.
Open-Ended View of Inquiry (OEI)

**QUADRANT 4**

**Citizenship Science (Fully Open Inquiry)**

*Teachers’ beliefs:*
- Curriculum expectations should meaningfully connect to the lives and interests of students;
- Science should relate to real-life events and issues;
- Students should be guided by teachers facilitating and mentoring them through the process of finding answers to their own questions;
- Students should be given some control over content in curriculum;
- Skills of scientific literacy should be developed through a knowledge base and skill set to support critical thinking;
- Students following ‘recipe’ labs do not achieve the most effective learning;
- Students should do independent investigations;
- Students should carry out scientific practices similar to those of scientists;
- Scientific knowledge is tentative, not fixed;
- Evaluation should include student improvement;
- Student creativity should be valued;
- Student collaboration is important to learning.

**QUADRANT 1**

**Utilitarian Science (Guided Inquiry)**

*Teachers’ beliefs:*
- Problem-solving should be emphasized;
- Student learning should apply to real-life situations;
- Students need to become scientifically literate by mastering critical knowledge (content and basic skills) and developing problem solving skills;
- Students need to be taught critical content and basic skills as preparation for future science studies (college and university);
- Answering questions quickly is evidence of academic capability
- Expressed teacher confidence in training and in mastery of scientific knowledge;
- Expressed teacher confidence in judging what students should learn as preparation for future studies in science;
- Students need to carry out scientific practices similar to those of scientists;
- Students following ‘recipe’ labs do not achieve the most effective learning;
- Students should do independent investigations;
- Scientific knowledge is tentative, not fixed;
- A teacher should control student learning (content, basic skills).

**Student-Directed View of Learning (SDL)**

**QUADRANT 3**

**Authentic Contextual Science (Structured Inquiry)**

*Teachers’ Beliefs:*
- Science curriculum needs to be personally meaningful to students (all grades and levels);
- Students should study and discuss current socio-scientific issues (real-life issues and events) as preparation for life in a complex world;
- Students need to be taught to develop logical arguments;
- Classroom organization should be based on the principles of authentic discourse;
- Student creativity is valued;
- Student collaboration is important to learning;
- Student improvement should be a part of evaluation.

**Teacher-Directed View of Learning (TDL)**

**QUADRANT 2**

**Content-Based Science (Confirmation Inquiry)**

*Teachers’ Beliefs:*
- Teachers should control and manage student learning;
- A safe, secure and organized environment should be provided to support student learning;
- Students should be taught knowledge (content and basic skills) in the curriculum as preparation for their next level of training in science;
- Expressed teacher confidence in training and in mastery of scientific knowledge;
- Correct answers to questions is evidence of learning in science;
- Students need to think carefully and with precision;
- Marks make good motivators.

Closed-Ended View of Inquiry (CEI)

*Figure 4. Characterization of teachers’ beliefs and teaching practices related to inquiry as practical work in science (quantitative and qualitative results).*
CHAPTER 5
CHALLENGES TO THE ENACTMENT OF OPEN-ENDED TYPES OF INQUIRY AS PRACTICAL WORK IN SCIENCE

Qualitative data pertaining to my third research question (What are the reported challenges to enactment of open-ended of inquiry as practical work in secondary school science?) was collected during Stage 1 (an open-ended survey question) and during Stage 3 (an open-ended question during the in-depth interview). In this chapter, I identify the challenges that emerged as major themes in the survey data and expand these themes with Stage 3 qualitative findings. I illustrate each theme with quotes representing the reported beliefs of the Stage 3 participants.

It should be noted that teachers associated with two stances (citizenship science and utilitarian science) reported and described enacting open-ended inquiry communicating a preference for teaching open-ended inquiry in science. While fully open inquiry was identified as the teaching preference for citizenship science, guided inquiry was identified as the teaching preference for utilitarian science. Conversely, two types of participants reported that they did not have experience or knowledge to support the enactment of open-ended inquiry and confirmed a preference for closed-ended inquiry including confirmation inquiry in the case of content-based science and structured inquiry in the case of authentic contextual science. Additionally, it should be noted that although some challenges to enactment were identified generally by teachers associated with all stances, other challenges to enactment were reported by teachers associated with particular stances.

Data Analysis and Results

The following major challenges to enactment of open-ended inquiry emerged during qualitative analysis of interview data survey data: funding for science; content and accountability; a
restrictive curriculum in terms of content to be covered; student interest and motivation; workload; teachers’ pedagogical content knowledge; class size and safety; time constraint of the semester system; and collaboration. These factors will be considered generally first from the perspective of science teachers associated with all stances and then, more specifically in terms of teachers associated with particular stances.

Additionally, teachers’ resistance emerged as a major challenge during thematic analysis of interview data that participants associated with a cluster of related minor challenges including: course plans, ‘extra’ practical work; control of learning; and constant curricular change. Teacher resistance was not reported by survey respondents and, as such, is examined apart from the other identified major challenges (see Table 5, p. 111, for a summary).

**Major Themes**

**Funding for Practical Science**

A critical lack of funding to support all practical science is reported as a highly significant challenge by all of the participants in this study. Identified as a problem that has been increasing during the past few years, participants report that funding is critically needed to: update equipment and re-stock science supplies; outfit science labs; and update computer technology.

**Equipment and Supplies**

According to these participants, outdated and non-functioning equipment (e.g., power packs, microscopes, digital scales) are in urgent need of replacement and science supplies (e.g., chemicals, glassware) are extremely limited at the present time. George reports “Much of the equipment, currently in science departments, is badly outdated, for example, my use of triple beam balances in chemistry.” Tina states: “We haven’t many supplies to work with.”
In addition, many teachers indicate that a lot of the science equipment available for practical work is “unsafe to use in its current state” (Sam). Power packs are presented as an example (Sam). Explaining his reticence to have students conducting investigations in his science lab, Mark reports: “I am working in a third world lab, more or less. The sinks don’t work; they shoot water everywhere. The gas jets are sketchy at best. A properly funded and properly equipped lab is a basic starting point.” This view is also reflected in Sam’s statement:

Safety is a prime concern in science. A lot of materials and equipment that I have in my lab are getting quite outdated for modern physics. The level of technology is up there. I see a lack of funds as being a major barrier to my teaching (of open-ended inquiry) simply because the equipment has to be updated.

Kristen, who currently reports teaching open-ended inquiry, agrees that “funding is a significant barrier money for equipment, chemicals, specimens, microscopes etc.”

At the present time, these teachers report that in many cases there is not enough money in their science budgets to purchase the basic equipment and supplies necessary to support traditional ‘recipe’ lab work let alone open-ended inquiry, which these participants generally view as requiring a much higher level of equipment and resource support. Linda is one of these science teachers who states: “We don’t have money to buy even basic materials and equipment.” As a result, many of the long-standing, traditional ‘recipe’ labs have been replaced by teacher demonstrations. Jeff is a science teacher who has had to make such a decision owing to a lack of basic science equipment and/or supplies. He states:

Funding is absolutely a barrier for me. Every year the budgets are cut. We’re supposed to buy more with less. You go to suppliers and the prices have gone up. In some cases, it’s to the point where you go: “You know what? I’m not going to buy that any more. So I’m not going to do that experiment anymore.” This has happened a lot recently. (Department) funding definitely needs to be improved.
In planning to enact open-ended inquiry, Nicole maintains that “Department funding is one thing that really needs to be in place before you start.” Sarah agrees and states: “Right now we don’t have the money for this type of thing (open-ended inquiry).” Laura, focusing on her experience enacting open-ended inquiry, confirms that this approach to inquiry is hard to do without equipment and resources, but it can be done. Her answer to the problem of a lack of funding in her department is reported as being a matter of modifying your choices. She reports: “A lot of the choices that we made (about enactment of fully open inquiry) were based on economical projects. Some of the students asked questions that could have been answered in much more sophisticated ways if we’d had the equipment to do them.”

Science Labs

Re-outfitting old science laboratories is reported as another critical need in order to create more useable space to support open-ended types of inquiry. All participants, who currently report teaching open-ended types of inquiry (citizenship science and utilitarian science), indicate that open-ended inquiry is very difficult for teachers to implement in many schools owing to the physical limitations presented by classrooms. Kristen considers the space problem to be a major challenge that needs to be addressed. She states: “You are definitely constrained as to what you can do physically when there is a space problem.” Tanis agrees and is emphatic in stating: “You have to have the space to do it (open-ended inquiry).” Enacting fully open inquiry this year for the first time, Laura reports that the members of her science department faced the problem of finding enough space for students to do their projects. She describes their approach in addressing this problem:

Our school is very old. We have big space issues all the time but we made use of every space we possibly could. So, if there was a prep room with a counter available, we might get a group of them (students) there and, then, every counter in the classroom was used.
In classes where open-ended inquiry is taking place, a frequent consequence of the lack of lab space is reported to be students conducting their investigations at home. Having space available so that students can ‘do’ their science inquiries at school rather than at home, is identified as being important to many of these participants (59 percent) for two primary reasons. First, it gives teachers an opportunity to provide direct input to the investigative process and second, it gives teachers an opportunity to monitor the degree of student input to the final product. Furthermore, Nicole states:

Students are more willing to approach you if their project is at school. They say: “Look at this. What do you think of this?” Then, you have the chance to respond accordingly. If the project is at home, it’s really difficult for that interaction to occur. So, there has to be space.

Tom agrees with Nicole’s position and adds,

I try to make sure that I can see as much of the process (as possible) in class so I have a pretty good sense that they (the students) are going to carry as much of this through on their own as they can. The reality is that some parents just can’t help themselves. They’re in there even if the kids don’t want them there.

Computer Technology

In addition to reported deficiencies in science equipment and supplies, the majority of participants associated with three stances (utilitarian science, authentic contextual science citizenship science) identify a severe shortage of computers available in science as a problem that seriously restricts students’ computer access in school at the present time. In addition, Mark indicates that the computers which they do have in their schools are “slow and loaded with very outdated software.” As a result, Jeff reports that many of the science teachers in his school prefer to remain in their classrooms where they deliver curriculum to their students, thereby avoiding the loss of class time that occurs when they are working with the outdated computers and software. Tina is one of these
teachers who states with frustration: “We don’t have the computers. Students can better search for information at home.”

Jeff states: “Technology is at the stage right now where you can find out anything about anything on the internet.” Therefore, he maintains that students should be able to do their own investigations at school and states:

Students should be able to bring their own laptops to school and should have access to high speed internet at any time. They should be able to access all of the data bases; scientific data bases; and all of the journals on line such as the journal of nature.

Some insight into the basis for the identified severe funding shortfall in science may be found in Tom’s statement that: “A fundamental problem would have to be the low priority that science receives in most schools in terms of funding for departments.”

Andrew communicates the concern of each of the 17 participants interviewed in stating; “Literally, there isn’t much money for science and for problem-based learning.” He adds: “Kids have big ideas and big ideas usually require equipment and cost big money. We need to find a way to let kids investigate their big ideas.” Finally, the impact of this continued problem of limited funding on teacher morale is captured in George’s statement that “You run into the barrier of money; it’s a very draining experience.”

**Content and Accountability**

The majority of the respondents to the survey also report content in the curriculum as being a major challenge to teachers’ enactment of open-ended inquiry which is connected to a second challenge (teachers’ accountability to teach the curriculum) that was reported by 43 percent participants surveyed. Interviewees in Stage 3 associated with all stances also identified science
content and teachers’ accountability to teach the curriculum as challenges to the implementation of open-ended inquiry.

However, it should be noted that, while interviewees from two groups of teachers (content-based science and authentic contextual science) discussed both of these challenges to their own implementation of open-ended inquiry, teachers regarded as holding a utilitarian science stance discussed these challenges as deterrents to their colleagues’ implementation of open-ended types of inquiry.

Reflecting on the science curriculum, Jill (content-based science) states: “My responsibility is to make sure that they (the students) have covered the materials (content) in the guideline to make sure that they are ready for their next course.” At the present time, they confirm that, too often, they are able to teach only the major expectations in the curriculum without adding the “extra burden” (Jill) of open-ended inquiry. Sarah agrees stating:

The curriculum is packed. What’s going to give? How much time is that (enacting open-ended inquiry) going to take out of the curriculum? There isn’t time for this.”

Commenting on the level of stress that she experiences in teaching the Grade 9 science curriculum, Jill states: “It’s so difficult. It’s so frustrating. I run out of time throughout the whole year.” She adds:

The curriculum is a time/resources thing. I have to finish the curriculum. You are responsible for knowing what the kids are doing at the end of this. If they get to Grade 10 and don’t know the periodic table then, I’m in trouble.

Each of the participants associated with a content-based science stance identify this daily struggle to finish the content in the curriculum in the time available in the semester. Jill reflects the expressed
view of all of the participants in this group saying: “You feel like a slave to the curriculum or at least I do.”

Participants associated with a utilitarian science stance, report the constraining influence of too much content in the curriculum. George identifies an emphasis on “science content” as predominating in his department and reports the frequent comment by his colleagues that “there’s too much content”. He associates his colleagues’ emphasis on content with their ‘chalk-and-talk training’ in science particularly in university. He maintains “We’ve got teachers who have gone through university. We’re all pretty much academically inclined. We learned science as facts and we teach facts, transmission of low-level knowledge and then just give it back to me.” With frustration, he states: “This approach doesn’t turn them (students) into critical thinkers and it doesn’t make them appreciate science. There’s no (student) engagement in this type of learning.”

As a head of science, Paul concurs and maintains that: “Being academically successful (in science at university) presents some problems for science teachers as they were academically successful at science as content, not necessarily, as process.” As one of these teachers who teaches science with an emphasis on science content, Linda (content-based science) agrees that her academic background was content-oriented but links her approach to teaching in science directly to her teacher-training program. She states: “I came out of teacher’s college thinking that I had to teach them (students) certain things, you know, facts.”

In discussing this topic (teachers’ emphasis on teaching science as content), Paul identifies teachers’ corresponding heavy reliance on a textbook. He states: “Teachers don’t want to go beyond the content and direction in the textbook. They are always going on about not having time to get away from the textbook or get away from their plans.” He maintains that: “Teachers’ over-reliance on textbooks and their anxiety about having enough time to complete the curriculum (content) is
because they see science as content, a collection of scientific facts.” In frustration, adds: “Even lab reports are based on the textbook.” However, Paul recognizes that,

It’s easier to teach from a textbook. It’s easier to evaluate that way. If you get a textbook, open to page 20, and here’s the stuff, and memorize the definitions. It’s easier to assess. Do you know the definitions? Do you not know the definitions?” It’s so much easier to have the lab and you do it because tomorrow we have to move on the chapter 3.

George adds: “In a textbook, the content is all there in black and white. It’s very predictable.”

**A Restrictive Curriculum**

A prescriptive and rigorous curriculum is identified as a challenge by a majority of survey respondents and all of the teachers associated with utilitarian science and citizenship science. Reflecting on the demands of the curriculum and the enactment of open-ended inquiry, Tom (utilitarian science) lays part of the responsibility for the *dearth* of open-ended inquiry in secondary school science on curriculum developers stating: “Realistically, the curriculum is not open-ended. It’s very, very prescriptive, rigorous, and often, disjointed. You can’t have a highly prescriptive curriculum and, on the other hand, say let’s teach inquiry-based science.” As a supervisor, Paul (utilitarian science) agrees but adds,

I think that easing up on content to teach this (open-ended inquiry) is a tough sell for science teachers, as a whole, because for a lot of us that’s what we do. It seems like the system is set up in such a way that that’s what we are supposed to do transmit information. We’re transmitting data, low level knowledge. They (students) are supposed to absorb that, then, regurgitate it in quizzing and testing.

According to Brian, it is the Ministry’s responsibility to resolve this dilemma for teachers. He states

The Ministry needs to tell us what we’re supposed to get through. There are variations in there (the curriculum). So, do we have to cover everything? Do they (the
students) need to know all of the knowledge aspect that we’re trying to promote here with the curriculum.”

Nicole concludes “I think that we’ve got to find a balance.”

**Student Interest and Motivation**

A lack of student interest and motivation in science is identified as a major challenge to the enactment of open-ended inquiry in science by most of the survey respondents. Thematic analysis of interview data indicates that Stage 3 participants associated with utilitarian science and citizenship science also identify the lack of student interest and motivation as a major challenge to a teacher’s decision to implement open-ended types of inquiry as practical science in the early years of high school. However, participants holding a citizenship science stance link this problem of uninterested and unmotivated students to teachers’ failure to make science relevant.

With regard to student interest and motivation, Tom (utilitarian science) reports that “Too many science students come into high school not liking science. Some of these students have had multiple years of being turned off to science.” He maintains that,

> We need to find some way to not send so many students to high school who are already turned off from learning in general and learning science in particular. I see students coming in (to Grade 9) all the time who already have years and years worth of turn-off in education and in science. They haven’t any interest what-so-ever. They’re not there for any other reason than they have to be there.

Paul, Tom, George and Sam (utilitarian science) indicate that, when students are motivated to learn science, they are most often motivated to learn science content. These students are reported to be driven by a need to get high marks to gain admission to professional programs like medicine, veterinary college, pharmacy, and engineering. Such mark-driven students are described as
presenting an ever-present problem for their teachers as they demand clear pathways to academic success, which they interpret as high marks. George states:

They (Students) want facts, facts, facts, low-level facts. (When) we’re doing an experiment, (they want to) follow the recipe; take the data; answer the questions. If they turn the page, the answers are there. Everything is very much predictable. The students really aren’t engaged. They don’t know why they’re doing these things. It’s just for the teacher. It’s for a mark. That is the driver of their learning to get an A.

These science teachers report that their colleagues continually express concern that mark-driven students and their parents may be quite unhappy with the open-endedness of, and time required for, students to complete investigations related to open-ended inquiry (Paul and Tom). However, Paul maintains that the reality is: “When the students are successful, parents are happy with the students and the administrators are consoled.”

Participants regarded as holding a citizenship science stance connect the problem of uninterested and unmotivated students to teachers’ failure to make science relevant to them. Andrew states: “Many science teachers do not place priority on connecting with student interests and making learning meaningful for students.” However, he maintains that,

We have to make science meaningful for students by connecting to their interests…If they’re (students) interested in a topic, they’ll take ownership of it; they’ll believe in what they’re doing; they’ll see relevance in science. They’ll be motivated to learn science.

Brian concurs adding “We need to teach kids to enjoy learning in science. We need to make science relevant to them.” Finally, Nicole advises teachers “We can’t look at them (students) as vessels to be filled. We have to inspire them.”
Workload

Teacher workload is identified as a significant challenge to the enactment of open-ended inquiry by most of the survey respondents and Stage 3 interviewees including participants representing each stance (utilitarian science; content-based science; an authentic contextual science; and a citizenship science).

Science teachers generally report that there is a great deal of time required to conduct ‘time-honored ‘recipe’ labs’ (Tom). Planning, organizing, and preparing for labs, cleaning up after labs; and repairing and refurbishing science equipment when necessary are generally reported to require hours of a science teachers’ time in a week. In addition to their regular classroom activities and lab work, participants indicate that they are often given additional general supervisory responsibilities within the school leaving them short of time on a regular basis (Kristen, Tom, Tina, Jill, Sarah and Mark).

Kristen (citizenship science stance) considers this workload to present a particular problem for teachers who would like to do open-ended inquiry. Tina agrees stating: “I’m always running around from the time I arrive at school. There is very little time to think. Forget about time to conference with students.” Reflecting on the possibility of teaching open-ended inquiry in her science classes, Sarah responds quickly “Time is short now. I don’t have time for this (open-ended inquiry).” These participants indicate that the workload for teachers has become worse in the last few years. Kristen reports: “There are more and more demands on teachers and, in some cases, a lack of time to get things done.”

Tom (utilitarian science) confirms: “The workload is substantial for a science teacher. I faced the decision to cut back on what I try to do for my students in order to stay full time and not drive myself to insanity.” Nicole (citizenship science) identifies one of the great consumers of a teacher’s
time, for her, as being parental feedback. She reports that “Parent phone calls are consuming a lot of
time. Parents want accountability. So, you have to make more phone calls to parents. That takes a lot of
time.”

Jill (content-based science) anticipates that her workload, which she regards as substantial
now, will present a major challenge to her potential for success if she attempts to enact open-ended
science. She states: “I just don’t have a lot of time to go and do a lot of conferencing with students.”
A number of the participants agree with her (Mark, Sam, Jeff, Linda, Sarah). Linda (content-based
science) concludes: “As it is now, I don’t think that I have time for this (open-ended inquiry).”

**Knowledge**

Survey respondents identify lack teacher knowledge as a major challenge to their enactment
of open-ended inquiry as practical work in science. In addition, all of interviewees regarded as
holding a content-based science stance and an authentic contextual science stance similarly identify
their lack of knowledge about enacting open-ended types of inquiry as a deterrent for them. It should
be noted that both of these groups of participants reported that they do not teach open-ended inquiry.

Collectively, these participants (content-based science and authentic contextual science)
raised the following questions: What does it (open-ended inquiry) look like in the classroom? How
do you introduce open-ended inquiry? How do you teach open-ended inquiry to students? How
much freedom is given to the students? What kind of management issues appear? How do you assess
it? How do you get transfer of learning? (Sarah, Jill, Linda, George and Jeff). Jill reflects the general
view of the participants in this group (content-based science and authentic contextual science) when
she states:
I don’t feel that I have the knowledge base or enough examples to see how this is being done. What do you need to teach the students? You won’t know which skills they need to do certain things like the skill of interpreting data.

Linda adds “I haven’t seen it (open-ended inquiry) done by anybody who was experienced and I would want to teach it the right way. It seems daunting.” She communicates that she is concerned about implementing a teaching strategy that is foreign to her. Firmly, Jeff states: “I need to know more about it (open-ended inquiry) before I teach it. I was never taught how to do this (in teachers’ college).” Sarah expresses the same concern stating: “I haven’t been taught I don’t have the knowledge.” She adds: “Right now, it’s all new and pretty formidable. Show me how this works before I implement it in my classes leaving me floundering. If someone has done this (open-ended inquiry), then share it.”

These science teachers communicate a lack of confidence associated with their lack of knowledge. As such, they report that they lack the interest in teaching open-ended inquiry and indicate that they will need a great deal of support and direction from the Ministry before they will be ready to begin the process of learning how to enact this type of inquiry. They maintain that they do not want to fail and confirm that they view the whole prospect of teaching open-ended inquiry as being somewhat intimidating. Linda states:

In addition to not having enough time to fit that in, my concern is about the resources in terms of providing kids with all of the equipment and materials that they might need. It is daunting to think about having time to gather it all up or having the money to be able to afford to supply kids with things.

She adds,

I think that there are people who just aren’t sure that they are on the right track and I think, just to get a sense of security that they are thinking along the right lines and
that they’ve got the right kind of topics (for students) to work with, would allow them to have the confidence to go ahead with this.

Both groups of teachers (content-based science and authentic contextual science) confirm that they have continued to follow the longstanding tradition of ‘recipe’ labs as practical work in science which was the foundation of their own education in science, the training which they received in teacher’s college, and the approach to practical science most commonly implemented in their professional world, as teachers.

However, it should be noted that each one of these teachers report doing student-driven investigations (open-ended inquiry) themselves as students. For two participants (Jill and Mark), this experience occurred in university. In each case, these participants confirm how enjoyable this experience had been for them and how much they had learned from the experience. In addition, each participant could recount their experiences, as students, in great detail in spite of the passage of time (see Appendix Table F6 for personal reflections of Stage 3 participants on ‘doing’ inquiry as a student), while being unable to recall any other details about what they had learned in their science classes at that time. They could only report general memories of spending their time in class (elementary and secondary), taking notes and answering assigned questions by reading from the textbook.

Participants considered as holding a content-based science stance indicate that they would be willing to try to enact open-ended types of inquiry but, at the moment, they do not have the confidence to do so and are not willing to teach open-ended types of inquiry without a great deal of information, assistance, and resource support. They report that they, generally, feel isolated, uninformed and “wary about trying it and failing” (Jill). Jill states in closing: “You have to know what you’re doing.” However, teachers regarded as holding an authentic contextual science stance
report that they do not feel confident enough to begin thinking about teaching fully open inquiry but are willing to begin teaching guided inquiry if they are provided with resource support and assistance.

**Class Size and Safety**

While class size is identified as a challenge to implementation of open-ended inquiry by the majority of the participants, science teachers associated with two stances (utilitarian science and citizenship science) linked this challenge to safety issues. Additionally, two teachers associated with utilitarian science linked class size and safety with funding during their discussion about the need to replace outdated science equipment.

With reference to class size, Paul (utilitarian science) confirms that, from a supervisory perspective, “class size is always a problem.” Tom (utilitarian science) agrees stating:

Class size is a big factor. A year ago, I had a Grade 11 university level class that started out with 36 students. You can’t even do simple labs with those kinds of numbers let alone open-ended, dynamic science. We don’t have the equipment to support these numbers.

Kristen (citizenship science) indicates that safety can become a serious issue in science. She states:

Once you exceed 24 in a lab, you are definitely constrained as to what you can do physically. You know, you can’t run a class for 36 kids having each pair run a Bunsen burner. That’s dangerous. So that does physically limit what you can do. So, class size and safety run hand-in-hand; safety and a lab that is properly equipped for safety. Many of our science labs are not well-equipped. These (factors) are important to this type of inquiry (open-ended inquiry).

The consensus of this group of participants is that an ideal number would be 20 to 25 students at the university level and less than 20 for college and essential level students. Several of
these participants report that many science classes have more than 35 students registered (Tom, Paul and George).

**Time in the Semester**

Lack of time directly related to the semester system is identified as a major challenge by 98 percent of survey respondents. However, this challenge was reported as a deterrent by teachers associated with only two stances (citizenship science and utilitarian science) during the Stage 3 in-depth interview.

Andrew (citizenship science) maintains that: “One semester is not long enough for some students to complete their projects. A year would be much better.” Tom (utilitarian science) asks: “Why are we still in a semester system when the main motivation for a semester system is not even on the radar anymore?” He adds:

There’s heaps of research out there showing that learning anything that is a continual sort of learning curve like science or math, when it is rammed down students’ throats in 5 months and then a year goes by before they get to study it again because of the semester system, there’s so much of that foundation knowledge and development that is lost. So, as a teacher, you have to start over again.

Nicole (citizenship science) reports: “There’s not a lot of time for conferencing with students in the semester. The pace has to be fast.”

Tom maintains that: “Administrators need to look at re-organizing our schools so that some subjects are taught on a year-round basis. Science would be one of those.” In addition, Brian (citizenship science) advises that the Ministry needs to provide some direction. He asks: “How much of the curriculum do we have to teach? Where does inquiry fit in and how? The Ministry needs to
tell us (teachers).” With determination, Paul concludes: “We can’t provide more time (for teachers) but what we can do is provide a way to show people how to do things differently.”

**Collaboration**

A lack of teacher collaboration is identified as a challenge to the enactment of open-ended types of inquiry by 78 percent of the survey respondents. Thematic analysis of interview data reveals that this challenge is similarly identified by 48 percent of the interviewees including all of the participants considered as holding an authentic contextual science stance.

Jeff and Mark report feeling very isolated, at the present time, with very little opportunity to communicate with their colleagues especially those in other schools.

Jeff states: “The problem with education is that it becomes very, sort of, insular and isolating.” He adds: “We accomplish so much more together than we do by ourselves. Everybody has to collaborate at the school level and absolutely administration.” He emphasizes that: “Administration sets the tone for the school. They need to be involved.”

Reporting a general lack of pedagogical content knowledge with respect to teaching open-ended inquiry, both of these teachers indicate that they would like to connect through video conferencing with other teachers in Pine Valley Board to see demonstrations of how to teach various aspects of open-ended inquiry. They report with frustration that this is not possible at the moment. To achieve this capability, Jeff maintains that: “The Board needs to upgrade its computer hardware and software and add high speed to our internet in all schools.” Mark adds: “Teachers need to be connected.” Sarah concludes “If you could get some of that collaborating and sharing between teachers back that would be good.”
**Teachers’ Resistance**

Teachers’ general resistance to this shift in curricular emphasis (implementation of open-ended inquiry) was not identified by survey respondents (Stage 1). However, teachers’ general resistance to implementation of open-ended types of inquiry without program support was identified by a majority of Stage 3 interviewees associated with all stances (utilitarian science; content-based science; authentic contextual science; and citizenship science).

Several factors were reported as being major and direct contributors to this general resistance. These included the time commitment necessary to re-write course binders to incorporate open-ended types of inquiry; teachers’ view of open-ended inquiry as ‘extra’ practical work; the teachers’ need to control and manage student learning; and constant curricular change. Paul (utilitarian science) confirms that,

The resistance is real. There are some teachers who just will go on: “I’m not doing it because it’s going to take too much time and that’s that.” This would be maybe thirty percent of the teachers. They just hope that it goes away and say: “I’m just going to keep doing what I’ve always done.” Some of those people will never change.

One of those teachers is Sarah (content-based science), who confirms: “As I see it right now, I’m not doing it (teaching open-ended inquiry).”

**Course Plans**

The first factor identified as contributing greatly to teachers’ resistance to implementing open-ended inquiry is the time commitment necessary to locate and/or develop new curricular resources to support the implementation of open-ended types of inquiry. Nicole (citizenship science) states:

Their (teachers’) course plans have been developed over many years and they believe that what they are doing is successful. The curriculum is pretty packed and a lot of
teachers have a lot of time invested in their course binders. They (teachers) will be very resistant to any initiative that requires the investment of additional time to change their binders. They would have to invest much more time to add inquiry-based science to their course plans. This will not be easily achieved.

Extra Practical Work

A second factor associated with this resistance is identified as teachers’ view of open-ended types of inquiry as extra practical work. Several participants (Jill, Sarah, Linda and Mark) (content-based science and authentic contextual science) indicated this view. Jill reflects this concern in asking,

How much time is it (teaching open-ended inquiry) going to take out of the curriculum? I never get through the curriculum as it is so I’m thinking of this (open-ended inquiry) as something extra. To try to do that as something extra, would be difficult. I have to finish the curriculum.

Sarah wonders: “How can I fulfill my obligation to cover the curriculum when I am teaching open-ended types of inquiry?

Teachers’ indicate that, if open-ended inquiry in science is to be a curricular goal in science, the ministry has to specify this directly indicating where and how open-ended inquiry (Linda, Sarah, Jill and Brian) is to be implemented. They report that the ministry has not done so in its most recent curriculum documents. Sarah states: “I haven’t seen anywhere in the curriculum that this is possible open-ended stuff and this is how you would do it.” Linda concludes: “The curriculum demands are pretty rigorous now in terms of content that we are required to teach to the students and have the students learn and there just doesn’t seem to be time to teach inquiry-based science.” Jill adds: “I just don’t know how a teacher would find time for this (open-ended inquiry).”
Control of Learning

Participants considered as holding a content-based science stance identify the importance of controlling student learning and managing behavior as the primary reason for their resistance to enacting open-ended types of inquiry. Although this challenge could be related to class size, these science teachers did not directly make this connection. Instead, they linked this challenge to safety issues. Sarah states: “Class size is there. Having them (students) fumble through (open-ended inquiry), so to speak, because that’s what you’re doing is not safe”.

Discussing her reticence to implement open-ended types of inquiry, Sarah also reports that: “The outcome that I am looking for from a lab exercise is something you can discuss. I want to have control and I want the kids to have control. Where it’s a cookbook lab, you get the results you want.”

With regard to open-ended student investigations, she states:

Some (students) might be going and fiddling on something and, then, never get anything done. How do you deal with that? There is only one of me in the classroom and there are 25 of them. Management is a big issue for me.

Linda reflects a similar concern about classroom management in a classroom where students are ‘doing’ open-ended inquiry. She states: “I am nervous to try something (teaching open-ended inquiry) that I’m not sure I can manage appropriately.”

All of the participants in this group (content-based science) express concern about teaching an unstructured form of inquiry. Before they attempt to implement fully open or guided inquiry, they indicate that they want to be provided with strategies that would serve to effectively reduce the chaos which they expect to be associated with the implementation of open-ended types of inquiry so that they can continue to provide a safe, orderly, and organized learning environment for their students (Sarah and Jill).
If she implements open-ended inquiry as practical science, Sarah wonders: “Can I fulfill my obligation to cover the curriculum?” At the same time, she maintains that her gravest concern is the possibility that, in teaching open-ended inquiry, she will find that her class is “totally chaotic.”

**Constant Curriculum Change**

Lastly, Stage 3 participants, including members from each group of participants identified during thematic analysis of interview data (utilitarian science; citizenship science; content-based science; and authentic contextual science), report constant curricular change as being a factor contributing to teachers’ resistance to implement open-ended inquiry. These science teachers confirm that many of their colleagues wonder how short-lived this new set of “ministry directives” (Paul) will be. Jeff (authentic contextual science) maintains that:

There has been so much change that the older teachers tend to be more cynical. They say: “Oh, we’ve seen this before. There’s no support. I’m working alone. If I stick my head in the sand long enough, it’ll all go away. It’ll change back.

Andrew (citizenship science) concurs and states “About one third of the teachers will just say no to open-ended inquiry.” He indicates that many of his colleagues do not see the benefit of these types of inquiry and communicate their plan to firmly adhere to a transmission model of curriculum delivery. Sarah (content-based science) is one of these teachers who states: “Why should I change what I am doing this time?”

The primary issue in terms of constant curricular change, for many of these teachers, is reported to be related to the importance they attach to predictability in the classroom. Tom (utilitarian science), who indicates that he is not so concerned about predictability, reports that “(My) background and attitude were important to my teaching decision to teach inquiry-based science.” Andrew (citizenship science) also identifies teachers’ concern about predictability as being
important to a teachers’ willingness to enact open-ended inquiry and states: “My own personal experience (‘doing’ inquiry-based science as a student) has framed the way I teach.”

In summary, I present Table 5 (see p. 111) as an overview of the major challenges identified by respondents in Stage 1 and Stage 3. In Figure 5 (see p. 112), I also present a summary of challenges related to enactment of open-ended inquiry by stance. Lastly, as summarized in Figure 6 (see p. 112), science teachers associated with all stances identified five challenges as representing a significant deterrent to the enactment of open-ended inquiry including: a lack of funding to support science programs, too much content in the curriculum, a heavy workload for science teachers, a lack of teacher collaboration at the department level and at the board level, and finally, teachers’ general resistance to curricular change owing to the constant curricular change to which they have been exposed during the past few years.
Table 5

Summary of Major Challenges to the Enactment of Open-Ended Inquiry as Practical Work in Science

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Stage 1 (%) response (n = 83)</th>
<th>Stage 3 (%) response (n = 17)</th>
<th>Stance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Department funding</td>
<td>99</td>
<td>100</td>
<td>US, CBS, ACS, CS</td>
</tr>
<tr>
<td>2. Content and Accountability</td>
<td>89</td>
<td>43</td>
<td>US, CBS, ACS, CS</td>
</tr>
<tr>
<td>3. Restrictive curriculum</td>
<td>79</td>
<td>28</td>
<td>US, CS</td>
</tr>
<tr>
<td>4. Student interest and motivation</td>
<td>99</td>
<td>47</td>
<td>US, CS</td>
</tr>
<tr>
<td>5. Workload</td>
<td>96</td>
<td>88</td>
<td>US, CBS, ACS, CS</td>
</tr>
<tr>
<td>6. Lack of knowledge</td>
<td>77</td>
<td>29</td>
<td>CBS, ACS</td>
</tr>
<tr>
<td>7. Class size and Safety</td>
<td>43</td>
<td>29</td>
<td>US, CS</td>
</tr>
<tr>
<td>8. Time in the semester</td>
<td>98</td>
<td>29</td>
<td>US, CS</td>
</tr>
<tr>
<td>9. Collaboration</td>
<td>78</td>
<td>48</td>
<td>US, CBS, ACS, CS</td>
</tr>
<tr>
<td>10. Teachers’ resistance Course plans</td>
<td>--</td>
<td>88</td>
<td>US, CBS, ACS, CS</td>
</tr>
<tr>
<td>‘Extra’ practical work</td>
<td>--</td>
<td>17</td>
<td>CBS, ACS</td>
</tr>
<tr>
<td>Control and management</td>
<td>--</td>
<td>24</td>
<td>CBS</td>
</tr>
<tr>
<td>Constant curricular change</td>
<td>--</td>
<td>18</td>
<td>CBS</td>
</tr>
<tr>
<td></td>
<td>--</td>
<td>47</td>
<td>US, CBS, ACS, CS</td>
</tr>
</tbody>
</table>

Note. US = Utilitarian Science; CBS = Science as Knowledge; ACS = Authentic Contextual Science; CS = Citizenship Science.
Open-Ended View of Inquiry (OEI)

Quadrant 4: Citizenship Science
Preferred type of inquiry: Fully Open
Contextual challenges to enactment for teachers:
- A restrictive curriculum;
- Class size and safety;
- Student interest and motivation;
- Time in the semester.

Quadrant 1: Utilitarian Science
Preferred type of inquiry: Guided
Contextual and personal challenges to enactment for teachers:
- A restrictive curriculum;
- Class size and safety;
- Student interest and motivation;
- Time in the semester;
- Content and accountability.

Quadrant 2: Science as Knowledge
Preferred type of inquiry: Confirmation
Personal challenges to enactment:
- Content and accountability;
- Lack of Knowledge;
- Time investment in course plans;
- Open-ended inquiry as ‘extra’ practical work;
- Control and management of student learning and behavior.

Quadrant 3: Authentic Contextual Science
Preferred type of inquiry: Structured
Personal challenges to enactment:
- Lack of knowledge;
- Time investment in course plans.

Teacher-Directed View of Learning (TDL)

Student-Directed View of Learning (SDL)

Closed-Ended View of Inquiry (CEI)

Figure 5. Challenges to enactment of open-ended inquiry by stance

Personal and contextual challenges (all stances):
- Funding of Science
- Too much curriculum content
- Teacher workload
- Lack of teacher collaboration
- Teachers’ general resistance (constant curricular change)

Figure 6. Challenges to enactment of open-ended inquiry (all stances)
In chapter 6, I examine and discuss types of program support recommended by survey respondents (Stage 1) and by interviewees (Stage 3) as a means of fostering the enactment of open-ended types of inquiry in science. Qualitative results from both Stage 1 and Stage 3 are quantized and merged for comparison. I, then, expand on the findings of Stage 1 with the findings from Stage 3. Lastly, I expand the results of quantitative analysis (quantized survey and interview results) with the results of qualitative analysis.

As was the case for challenges to enactment, some types of program support to foster enactment of open-ended inquiry were generally recommended by participants associated with all stances while other types of program support were more specifically identified by teachers associated with particular stances. Among the recommendations for program support discussed in chapter 6 are: professional development, mentors, classroom visitations to support teacher collaboration and cooperation and funding.
In this study, qualitative data pertaining to teachers’ recommendations of for program support for implementation of open-ended types of inquiry was collected in Stage 1 and Stage 3. In open-ended questions contained in the Stage 1 questionnaire, participants were asked to identify types of meaningful program support to foster the implementation of open-ended inquiry. In Stage 3, during an in-depth interview, science teachers were asked to identify and describe types of program support that could meaningfully facilitate their enactment of open-ended types of inquiry in secondary school science.

In this chapter, I identify the types of program support that emerged as major themes in the Stage 1 survey data and expand these themes from the perspective of the 17 participants interviewed in Stage 3. I illustrate each theme with quotes representing the reported views of the Stage 3 participants. Again, it should be noted that two groups of participants interviewed in Stage 3 (citizenship science and utilitarian science) reported and described experiences, as science teachers, regularly enacting open-ended inquiry as fully open or guided inquiry. Two groups of participants (content-based science and authentic contextual science) reported that they did not have experience or the knowledge to support enactment of open-ended inquiry.

Data Analysis and Results

The following major types of program support were recommended by survey respondents: professional development, mentors, strategies to foster collaboration and co-operation, and funding of practical science. Each of these types of program support also emerged as themes, during thematic
analysis of interview data, as types of program support that could successfully foster open-ended inquiry in science.

In this chapter, I discuss each of these four themes first, from the standpoint of participants in general and then, from the perspective of each stance (utilitarian science, content-based science, authentic contextual science, and citizenship science) if applicable. Professional development and mentor support are discussed first followed by strategies to foster collaboration and cooperation. Lastly, department funding is discussed recognizing that the condition of science labs and resources can limit a teachers’ ability to enact open-ended inquiry (as discussed in Chapter 5).

Professional Development

Professional development was recommended by a majority of respondents to the questionnaire and by all of the Stage 3 participants as an important type of program support to foster the goal of broad-based implementation of open-ended inquiry. While a few recommendations with regard to professional development were generally made by participants of all stances, teachers associated with each stance had a different view of the approach that this professional development should take. In discussing professional development, the recommendations of participants associated with all stances will be discussed first followed by recommendations by stance.

Recommendations: All Stances

Most of the Stage 3 interviewees recommended that, to be effective, professional development should be delivered in an extended time frame, fully funded, scheduled during the school day, and mandatory. In discussing an extended time frame, Paul (utilitarian science) maintains “It’s got to be multiple days, 3-4 days, and all (teachers) would have to be involved” (George). George (utilitarian science) agrees and states: “We need time to be trained properly. One
day is not going to work. That’s an exposure.” Andrew (citizenship science) agrees and advises “This is going to take time.” George confirms “Personally, I’d want the days to be continuous because I think that I would retain more if it was in one chunk. Also agreeing that “One day is not going to work. We do not have enough time to be trained properly,” Mark and Jeff (authentic contextual science) recommend 2 or 3 days. Recounting her experience in learning how to teach open-ended inquiry, Nicole (citizenship science) advises: “It’s got to be multiple days. Teachers need time for lots of practice.”

Participants regarded as holding a content-based science stance collectively recommend a week-long summer institute where science teachers can get direct experience and explore the implementation of open-ended inquiry. These teachers maintain that a summer institute would give them time to develop knowledge about and gain experience with open-ended inquiry before teaching it in a science class. Linda (content-based science) confirms that she would like professional development to be delivered in a “chunk of time that was devoted to understanding it (open-ended inquiry) better and learning more about effective ways of helping kids.” She adds that,

A summer institute would be a good way to do it. If you could package it up in a week-long session and give teachers the opportunity to run through this type of science with all of the coaching that one would need to run this sort of program, maybe a summer institute would do it.

**Recommendations by Stance**

There was substantial difference in the specific recommendations for professional development identified by each stance.
**Utilitarian Science**

Participants considered as holding a utilitarian science stance suggest professional development that has the following features to support science teachers who are learning how to teach open-ended inquiry as practical science.

1. *Delivered by Experienced Experts*

   All of these science teachers maintain that professional development needs to be delivered by highly knowledgeable and experienced experts who can give many examples of successful enactment of open-ended inquiry. Tom states:

   I’ve seen all kinds of delivery over the years, with all sorts of curriculum changes where the supposed experts come through and they offer you one example and, then, you say: “OK and do you have any other examples?” and no, they don’t. All they have is that one example. Well, that’s not going to convince many people that this is the way to go. You have to have good people doing the PD.

   George maintains that “You need to have someone (a leader) who has experience and knows what the difficulties might be and what to do about them…They (PD leaders) must be able to give us many different ideas about what we could do.”

2. *Grounded in the Classroom*

   They also recommend that professional development be delivered with an open-ended approach which is grounded in the classroom that addresses these questions: What it is? What does it looks like in the classroom? How do you do it and how do you evaluate it? (George, Sam, Paul). Sam suggests that: “It should be organized as a two-phase process with the first phase directed toward general science (Grade 9 and 10) early in the (PD) schedule followed by withdrawal to specialty areas of the science curriculum (biology, chemistry, physics and environmental science) later in the schedule.”
George emphasizes the importance of professional development in support of implementation of open-ended inquiry that is grounded in the classroom. He states “I must be able to apply what I am learning directly in my classroom. I don’t have time to re-invent the wheel.” Sam agrees stating: “I need to know about this (enacting fully open inquiry) and then I need basic training to go along with this that I can use in my classroom.”

According to these participants (utilitarian science), such instruction should include identification of investigative skills that, most critically, need to be developed in order to support student success in open-ended inquiry and instructs teachers, supported by resources, on how to scaffold these skills. Sam states: “This PD (to support fully open inquiry) needs to fill in the gaps in my knowledge and supply me with some direct training in teaching the skills of independent investigation.” Tom reminds supervisors and teachers that “You (as a teacher) can’t just throw them (students) into open-ended investigations without skill development to support that.”

3. Provision of Exemplars

Exemplars are recommended as being a high priority “to illustrate the realm of possibility for enactment of inquiry-based science” (George). He reports that: “The exemplar approach can be very valuable if I’m learning to teach something new. They would help me to see what is possible.” Paul agrees with this position stating:

You need to have solid exemplars to show people what success looks like. What does it actually look like? How do you evaluate it and judge it so that everybody is going to be happy at the end of it? The students are successful and the parents are happy with the students.

Sam states: “I would value exemplars because I need to see the realm of possibility to determine what could actually happen.”
4. Alternative Teaching Strategies Presented

Alternative strategies are recommended that assist teachers in finding a balance between teaching science as content and teaching science as process so that class time can be ‘found’ to support student-driven investigations. Paul states:

We can’t provide teachers with more time for open-ended inquiry but, what we can do is show (them) how to do things differently. Teachers need to be shown how to integrate the concepts and re-organize the units so that they will have time for student-driven investigations and the realization that inquiry-based science does not represent a burden of time. Guidance for teachers on different ways to better enact process-based learning as opposed to content-based learning would be very valuable.”

With reference to guided or structured inquiry, Tom confirms that “This (teaching open-ended inquiry) is done differently.”

Content-Based Science

The following two recommendations for professional development are suggested by teachers associated with content-based science to facilitate their own enactment of open-ended inquiry: step-by-step instruction and a resource guidebook which is used as a training manual.

1. Provision of Step-by-Step Instruction

These participants report that step-by-step instruction would give them enough confidence to at least try to enact open-ended types of inquiry in science. Sarah states: “Tell me what to do and how to do it. I think you have to do it step-by-step. I have never been taught (how to teach open-ended types of inquiry). I don’t feel that I have the knowledge base or enough examples to see how this is being done.”
In addition, Jill cautions that professional development needs to be conducted by a leader who is sensitive to the needs of the teachers. She states: “There has to be a gentleness of approach I do not want to feel stupid by the end of it (the professional development activity). I want to know that this is something that everybody can do.” Linda reports: “I don’t know how I would do this. Most of what’s done now is recipe labs that are very ‘formulaic’ in nature.”

2. A Resource Guidebook Used as a Training Manual

A “take-off-the-shelf” (Sarah) resource guidebook is also suggested collectively by all of the teachers in this group. They would like this resource guidebook to be used as a training manual to support teacher learning and provide a basis for continued teacher development. Participants indicate that this guidebook should contain curricular materials that would serve as resource support for teachers at the classroom level during the enactment of open-ended inquiry. They maintain that such a guidebook needs to include student worksheets to scaffold skill development, topic lists, references, research websites, rubrics, and assessment instruments.

According to Linda, “Sample handouts to support student learning, rubrics and guidelines in assessment would help support teachers learning to enact this type of inquiry (open-ended).” Jill adds: “This kind of support is always wonderful and makes your life (as a teacher) so much easier. We need ‘things’ we can copy to give to students.” Linda states:

I would like it (a guidebook) to have pages that could be photocopied to help guide the students doing investigations. I think that, for somebody like me starting out, it might be the scaffolding that a teacher would need to get started and to feel confident about doing it (enacting open-ended inquiry).
These participants indicate that they would like such a resource book to include rubrics and assessment instruments to “give teachers a sense of security that they are thinking along the right lines” (Linda).

They also indicate that they are looking for professional development that incorporates curricular resources that “fully support” (Jill) the teaching of open-ended types of inquiry adding that they do not have enough time to develop their own resources and initially have no idea what they would need. Sarah states: “I think that there has to be professional development, something in black and white to show you how to do all of it.” She adds: “Show me how it (open-ended inquiry) works before I implement it in my classes.” Linda confirms that she needs professional development that: “gives one a sense of security that what they are doing is moving along the right lines.”

**Authentic Contextual Science**

Teachers associated with authentic contextual science also recommend professional development to facilitate their own enactment of open-ended inquiry.

**Open-Ended Inquiry Described**

Jeff describes his preferred approach to professional development as one which a “walks us through the stages of the process.” Both Jeff and Mark indicate that such professional development needs to provide answers to teachers’ questions. Jeff presents examples of the questions that need to be answered for teachers including:

- What (would a) typical day look like in class? How much freedom is given to kids?
- What (would) a student look like who was involved in that (open-ended inquiry)?
- How does management work? What kind of management issues appear? How much freedom (are) the students given? and What (would) a teacher expect their students to come up with?
Citizenship Science

Teachers associated with citizenship science, report that professional development to foster teachers’ enactment of open-ended inquiry needs to: provide teachers with active and direct experience; present alternative strategies for networking; teach teachers to be facilitators and mentors; and develop confidence and inspire teachers to enact open-ended inquiry;

1. Provides for Active and Direct Experience

These participants suggest that teachers, who are learning how to implement open-ended inquiry, need to be provided with the opportunity to experience open-ended directly from a student’s perspective. Nicole states: “Teachers need first-hand experience because it’s a different way of doing things than most of us do now.” She adds “Most of lab work in high school is textbook lab types. This (open-ended inquiry) is very different.”

In support of teacher growth in relation to enactment of open-ended types of inquiry, Tina states: “Teachers have to begin this process (learning how to teach open-ended inquiry) by gaining an understanding of what is involved” and suggests that:

It would be interesting to actually have them (teachers) do a project themselves and actually live it. Create a little experiment and come up with all of the variables just like students would and, then, they would fully understand it. I think that, once you live it, it begins to make sense.

While Brian also recommends that “Teachers need to be able to experience it (‘doing’ open-ended inquiry) directly”, Kristen confirms that, for her, “Professional development, always, needs to give us the essence of what we teach and that is true here.”
2. Presents Alternative Strategies for Networking

Information about alternative strategies for networking at the school, board and community level in direct support of student investigations is also recommended. These science teachers, with self-reported experience in teaching open-ended inquiry, maintain that teachers need to have strategies to seek out-of-classroom support which should include an open-door department policy to support student investigations.

Nicole states: “There needs to be an open door policy within the department. The chemistry teacher, the physics teacher and the biology teacher are all teachers and they need to be open to answer student questions related to their projects.” She adds: “This is particularly important when students are working on competitive projects.” Andrew advises that teachers need to remember that “All teachers are there for the kids. That’s why we’re there."

He adds “Students need to be able to access someone who has expertise in any area of science and they should be able to ask for and get the assistance that they need to support their studies.” Susan confirms that “Some of the student projects are, at times, out of our (areas of) expertise. We’ve been able to go outside the school to find support.” Nicole suggests:

If you have a community college or university in your city, you want to develop a partnership with them including a mentoring program where students can email certain members of the faculty who have indicated a willingness to answer questions in their area of expertise.

Andrew also recommends such networking needs to include “Resource support and sometimes funding in support of student investigations.” He states:

I’ve been able to get support. When they (administration) saw what the kids were doing, I was able to say look, I need these materials and they (administration) helped
me find some extra money for it (student investigations) because literally there isn’t much money for problem-based learning in the department.

Additionally, he reports that he has been successful in lobbying for technological support, from a local university, to support his students’ investigations.

3. Teach Teachers to Be Facilitators and Mentors

The majority of participants in this group stress the importance of teaching teachers to be facilitators and mentors. George, who reports teaching guided inquiry and anticipates teaching fully open inquiry, maintains that: “The teacher is a fundamental part of student learning and no longer a ‘sage on the stage.’ They (teachers) need to be aware that they should be mentors and facilitators.” Kristen confirms “I see my role as a science teacher as the role of facilitator to help them (students) to get the tools to find information to answer their questions.” Tina identifies her role during open-ended inquiry as “assisting students with their own learning.”

In the role of facilitator, teachers, experienced in open-ended inquiry, maintain that science teachers have to learn how to empower students to ask meaningful questions and seek answers to their questions. Andrew states:

You have to give them time to formulate questions and to ask questions of you because you become the facilitator and mentor. You’re not the expert. So, they’re (students) there to ask you questions about their investigations not to ask what the answer will be. They’re empowered to do their own investigation. You (as the teacher) just have to figure out how to get them to ask a question.

Paul, who also reports teaching guided inquiry and indicates that he plans to enact fully open inquiry, considers that empowering students to ask questions is important and reminds educators that: “Science classrooms need to be places where you (students) ask questions and are given the tools to find your own answers or at least find an answer.” Nicole agrees with this position stating:
“As a teacher, you want to enable them (your students) and empower them to ask their own questions and make their own discoveries.”

These participants recommend that professional development needs to identify teaching strategies that encourage students to ask questions and report that this is not easy. Tanis states: “I have been teaching for 22 years but I still needed help in getting them (the students) to give up their ideas as opposed to me giving it to them.”

In addition, Nicole advises educators that, in supporting student success during open-ended inquiry, “the teacher needs to be able to direct students to possible areas where they can find answers to their questions because the teacher should not be the end of the line for the knowledge base.”

4. Develops Confidence and Inspires Teachers

Lastly, these participants indicate that there must be a focus on building confidence in teachers and inspiring them to overcome the resistance created by years of personal experience with the methods of traditional science so that they will become motivated to begin the process of learning how to teach open-ended inquiry.

Nicole indicates that professional development must convince teachers that open-ended inquiry is worthwhile. She advises that:

If a teacher doesn’t believe that it’s a worthy approach, they’re not going to be engaged in it and they’re not going to be a part of it. You got to make the teachers believe in it (open-ended inquiry). We have to remember that most of them (science teachers) don’t do that (open-ended inquiry) now or teach science as process.”
Laura adds:

It took me a long time to get the confidence to begin this (teaching fully open-ended inquiry). Now, I am remembering students that I had in the past who would have bought right into this idea (of doing fully open-ended inquiry). I would now like to know what they could have done having seen it.

According to Andrew, having teachers begin to do some of their own research will contribute to inspiring and motivating them to teach open-ended inquiry because: “When teachers are doing their own research, they’re excited about what they are doing and want to build that into their science departments, their science courses and their classrooms.”

*Mentors*

The need for mentors to support enactment following professional development was recommended generally by almost all Stage 3 participants associated with all stances but there were differences in the type of mentor support suggested by teachers associated with particular stances. George (utilitarian science) indicates that mentors “should be available on-line to make suggestions and identify resources.”

Participants communicating a content-based science stance recommend that classroom mentors should be provided by the Pine Valley Board. They report viewing these mentors as remaining in a particular science department for an extended period of time; working with one or more teachers; and modeling the teaching of open-ended inquiry. They also describe mentors as providing direct support for teachers who are learning how to enact open-ended types of inquiry particularly fully open inquiry. Jill maintains that,
I need the support to be in my classroom. I need somebody here to bounce ideas off of. Not even just to help but somebody to show me (model) how it is done. Somebody who has done it (enacted open-ended inquiry).

Sarah agrees stating: “I want this (open-ended inquiry) to be shown to me in the classroom.” These participants confirm that they are very nervous about attempting to implement open-ended inquiry and report believing that mentor support in their classrooms would ease their nervousness. Linda states: “To do this (begin teaching open-ended inquiry), I need someone to stand beside me while I am doing this and walk me through the process.”

Board-based mentors are recommended by participants considered to hold an authentic contextual science stance. These science teachers suggest the development of a pool of board-based mentors to support, on an on-going basis, teachers’ enactment of open-ended types of inquiry. They view these mentors as being available on a short term basis by request to (a) consult with individual teachers or departments; (b) provide resource support as needed; and (c) advocate on behalf of teachers for identified types of program support. George states: “Let me talk to a mentor that (who) is a teacher and has successfully done this.” He sees this person as a “curriculum leader who supports the teacher by email or through some other form of communication; giving advice as needed; and identifying on-line resources to support classroom enactment.” He adds “I would like someone, not to hold my hand constantly, but someone that I can contact who has done it before to say ‘OK, in this situation you might want to try this’. They would see the realm of possibility.”

Development of a pool of expertise is the recommendation of two groups of participants (citizenship science and content-based science). Teachers communicating a citizenship science stance view this pool of expertise as being board-based and consisting of science teachers who are willing to mentor their colleagues as they are beginning the process of enacting open-ended inquiry.
According to this group of participants, these science teachers would currently be under contract with Pine Valley Board; have multiple years of demonstrated expertise in teaching open-ended types inquiry; and agree to share their knowledge (including methods of assessment) and curricular resources (student worksheets, rubrics and assessment instruments) with their colleagues. Andrew states: “A lot of teachers want guidance.” Nicole suggests that: “The gurus out there need to be tracked down to see what they are doing. Other teachers need to see what they are doing.”

In addition to mentors in their classroom, science teachers considered as holding a content-based science stance would like these mentors to be available over the long-term on an “as-needs” (Jill) basis to consult about particular management issues that develop during the enactment of open-ended inquiry. Jill indicates: “Right now, I don’t know how on earth I would do this. I couldn’t handle this.” FW states: ‘I need someone I could contact to give me the support that would make one feel comfortable with this (teaching open-ended inquiry).” Sarah adds: “Just don’t leave me by myself to do this. Tell me how to handle (manage) this.”

**Teacher Collaboration and Cooperation**

Participants generally recommend that these strategies be implemented to foster teacher collaboration and cooperation including: classroom visitations, on-line communication and a teachers-coaching-teachers initiative.

**Classroom Visitations**

Classroom visitations were generally recommended as one of these strategies by teachers associated with all stances. Release time was suggested to support class visitations both at the school level and at the board-level. Brian (citizenship science) reminds curriculum leaders that “Collegiality
within the department; lots of cooperation and lots of collaboration are important to this (the successful implementation of open-ended inquiry).”

Sarah (content-based science) indicates that she would like to visit classes in other schools. She states: “What they are doing might be something totally different. You can see the variety (of approaches) out there; how other people faced it (teaching open-ended inquiry).” She adds “I think that you can do more sharing that way. That’s good.” Jeff (authentic contextual science) states: “Release time would be lovely. To go and shadow a teacher who is actively doing this (teaching open-ended inquiry).” He suggests

You could form a group of teachers who are all in the same boat. What we could do is work collaboratively after this (classroom visitation). We move ahead faster and further if we were collaborating than if we were by ourselves.

Additionally, Paul (utilitarian science) as teacher with supervisory responsibilities recommends:

There’s got to be some money put aside to enable demonstrations in the classroom where people (science teachers) could actually see it in action and be able to ask questions of the teacher who is doing it (teaching open-ended inquiry). That’s how I would like to do it in terms of how I’d like to learn how to do it. Seeing things in a video or reading them in a dry old textbook; it doesn’t work.

**On-Line Communication**

Teachers associated with utilitarian science recommend on-line communication to support teachers enacting open-ended inquiry. Tom states: “Some on-line resources that are available, are well-advertised, and aren’t difficult to get to, find and utilize once you get them.” In addition, they recommend providing for on-going teacher development by creating on-line seminars that include video clips with voice over by the teacher that model the teaching of open-ended types of inquiry
which teachers can access on their own time and at their own pace. Paul suggests that: “Having demonstrations on-line gives teachers the chance to arrange their own time but it’s got to be an active sort of demonstration where teachers can actually see it.”

George adds that: “On-line (demonstrations) need to be included (as program support) because the world is going on-line. One o’clock in the morning might work for me because I’m a night person.” Paul reports that he recommends on-line instruction and demonstrations because: “we can’t restrict the teachers and, then, free up the students. Both of them have to be sort of free and open and dynamic.” George maintains that:

You don’t always have to have to have a meeting of a group of people. You could present all this information on-line in You-tube or teacher tube or web sites so that people who are interested in it could actually see it in action. It takes nothing to actually set up a video camera in a classroom and take a video clip and have the teacher run an audio commentary over the top of it after the fact. Then, a group of teachers from other schools could consult with one another (on line) and share ideas.

George adds: “This is a way of individualizing it (professional development) for the teacher.” Both Paul and George identify the importance of creating a team building approach in supporting teachers’ enactment of open-ended types of inquiry. Paul maintains that: “With video conferencing capabilities in each school, teachers from different schools could get together on-line (to) share resources, share their experiences, and celebrate their successes. Paul maintains that: “It works so much better if everybody shares everything. You could feed off each other and see successes and see what doesn’t work and try new things. You need someone to knock ideas around with.”

In addition to supporting teacher sharing, George suggests that on-line communication capabilities “make the creation of a virtual classroom possible for teachers and provide students and teachers with the opportunity to connect on a global basis with scientists and researchers.”
**Teachers-Coaching-Teachers**

A *teachers-coaching-teachers* initiative at the department level and the board level for Pine Valley Board, supported by video conferencing, is recommended by teachers associated with citizenship science. Kristen indicates that video conferencing would be a very effective means of supporting a teachers-coaching-teachers initiative at the board level and advises that “Video conferencing needs to have information available like a web page that has links to resources that could be updated, upgraded, and graded.”

Tanis adds: “Teachers can support each other, as they begin to enact open-ended types of inquiry, which we have been doing here and it has worked out really well.” In addition, Nicole recommends: “If there are teachers who were interested in working together, they could exchange ideas and information. It could become a mentoring system where they coach one another. They collaborate and coach one another.”

Nicole maintains that: “Everybody brings different strengths and values to a team. Collaboration, co-operation, and encouragement within a team are the outcomes. Encouragement is very important. It (the team) has to be open and ready to examine all ideas.” Andrew reminds supervisors and teachers: “There is too little collegial support. We need to move away from this (isolation). The whole idea in education should be that you have to share.” He adds: “Any time you can get people together you have a potential team. If you’ve got some really good idea, you can share it with one another (teacher)”. Laura confirms that: “It is important to have teachers working together.” Andrew agrees but states: “Moneys need to be available for this”.

Funding of Practical Science

As discussed in chapter 5, funding was generally reported to be a challenge to the teaching of open-ended types of inquiry. Funding was, as expected, identified as a critically needed type of program support by most survey respondents and Stage 3 interviewees. As described earlier, they recommend that funding is necessary to update equipment in particular physics equipment; re-stock science supplies (e.g., chemicals) and other science supplies (e.g., glassware, biological specimens); and up-grade outdated labs for support student investigations. In addition, teachers add these additional recommendations: special funding for departments teaching open-ended types of inquiry; an equipment depot for specialized science equipment; purchase of curriculum resources (print and non-print) to support students’ investigations; and high speed internet.

Special Funding for Student Investigations

Tom maintains that: “Some fundamental changes are needed in how funding is allocated to science departments in order to fund student investigations.” Most of these science teacher expressed concern that science departments do not have sufficient science equipment and resources to support even traditional confirmation ‘recipe labs. Not surprisingly, many participants report that, at present, student investigations are extremely difficult to fund. In some schools, currently, teachers indicate that students are expected to fund, for the most part, their own open-ended inquiries. In other cases, teachers report that they are able to get some extra funding from school administration.

Susan maintains that: “Really, we need to know that we have finances to fund, at least, some of the basic equipment and some of the basic supplies that we would need to support student investigations.” Nicole agrees and states: “If a science department is engaged in student
investigations, there should be some more money to support that. The board needs to recognize that schools that are going to engage in open-ended types of inquiry will need extra funding for that.”

A Central Equipment Depot

Teachers associated with citizenship science recommend establishing a central equipment depot to serve as a repository for the specialized equipment that is often needed to support student investigations. In talking about his many attempts during the past few years to get support for student investigations, Andrew states: “You can only knock on so many doors before you wear out your welcome. So, funding to get equipment would be nice.” Kristin addresses this concern stating: “I suggest that some specialized equipment to support student projects be purchased and located at the board office so that it is accessible to all the science teachers.” Nicole supports this idea stating:

The equipment needs of some student investigations cannot be met currently at the department level particularly if the students are competing in regional or national science fairs. A stock of specialized equipment could be centrally purchased and signed out on an as needs basis as is the case in other curriculum areas now.

In speaking about her experience with the enactment of fully open inquiry, Laura expresses frustration with regard to the issue of available equipment, stating: “Some of the students asked questions that could have been answered in much more sophisticated ways if we’d had the equipment to do them.” Again, reflecting on his experience as a teacher implementing fully open inquiry in science, Andrew states: “I’ve come up against some big equipment issues.” Tina confirms “It would be really nice to have a really high level of equipment available.” Andrew recommends that “The Learning Resources Centre at the board office could look after this.”
**Textbooks and Other Curriculum Resources**

Having textbooks and other print resources available was very important to all participants associated with a content-based science stance. As discussed earlier, these teachers recommend a “take off the shelf” (Sarah) resource guidebook that contains curriculum materials that could be used to support teachers at the classroom level as they are teaching open-ended types of inquiry. Linda suggests that such a guidebook should contain: “student worksheets; topics lists; references; websites; rubrics; and assessment instruments.” Jill adds that: “A guidebook would be like a roadmap for teachers.” Linda maintains that “I, personally, would feel more comfortable with something that is more concrete.”

Reporting that currently approved textbooks do not offer support for open-ended types of inquiry, Sarah states: “We need textbooks to support this (open-ended inquiry) with examples of things you can do.” Jill communicates the same concern and states: “That stuff (activities to support open-ended inquiry) needs to be built into textbooks, which just makes everybody feel better. Print stuff (to illustrate open-ended types of inquiry) always helps because you can look at it and feel reassured. OK, yes. I haven’t missed it.”

**High Speed Internet**

Participants from three groups (utilitarian science, authentic contextual science, citizenship science) strongly recommend additional funding to upgrade computers and computer software in the department and in the school. These teachers generally agree with George’s statement: “Our computer technology and software is totally outdated. This needs to be changed.” High speed internet is recommended with the right of access to scientific data bases (board or ministry funded) to provide teachers and students with the opportunity to reference current scientific research reports and journal articles and support teachers and students who are actively engaged in investigating.
Mark advises that: “Teachers and students need to be able to sit and think and investigate what (relevant) information is out there. Jeff adds “They (teachers and students) need to have access to the internet high speed access to scientific data bases which are funded by the board.” Jeff and Mark stress the importance of making it possible for students to connect with the world outside the classroom and confirm that the high speed internet makes all sorts of things possible for students doing investigations and the teachers supporting them. Jeff states: “We have to connect the teachers and students to the world-wide community of science outside the classroom and allow them the opportunity to collaborate with anybody in the world.” However, he indicates that this is not possible at the present time and reports that: “Right now the internet is too slow. Log-in is incredibly slow and the software is outdated.” Concluding, he states: “We (in education) need to get closer to the cutting edge of technology.”

All participants communicated their surprise and disappointment that the ministry has not provided funding for departments to support the implementation of the new curriculum guidelines in science. As a teacher who teaches fully open inquiry, Andrew states: “If the direction from the ministry is an inquiry-based approach in science, there should be money to support teachers and the development of that through resources.” Such funding, he adds: “Should be channeled to the board which goes directly to the science department.”

In summary, I present Table 6 (see p. 137) as an overview of teachers’ recommendations for program support to foster the implementation of open-ended inquiry as practical science. In Figure 7 (see p. 139), I also present a summary of recommendations for program support related to implementation of open-ended inquiry by stance. Additionally, in Figure 8 (see p. 139) I present a summary of program support recommended for enactment of open-ended inquiry by participants from all stances.
It can be seen that four recommendations for program support represented the opinion of teachers associated with all stances including: professional development, mentors, classroom visitations to facilitate teachers’ collaboration and cooperation and funding targeted for student investigations. In addition, several recommendations were discussed as representing the view of particular stances including: high speed internet (utilitarian science, authentic contextual science, citizenship); on-line communication (utilitarian science); a teachers-coaching-teachers initiative (citizenship science); a central equipment depot (citizenship science); and textbooks (content-based science). Lastly, although teachers associated with each stance recommended professional development to foster the enactment of open-ended inquiry, teachers associated with particular stances had a different view of the approach that this professional development should take. These differences were discussed.

In chapter 7, findings pertaining to teachers reported beliefs and teaching practices related to inquiry, challenges to enactment of open-ended inquiry and types of program support recommended to foster the enactment of open-ended inquiry are discussed. These findings are linked back to the literature.
Table 6

**Summary of Major Types of Program Support Recommended for the Enactment of Open-Ended Inquiry as Practical Work in Science**

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<th>Program support</th>
<th>Stage 1 (% response)</th>
<th>Stage 3 (% response)</th>
<th>Stance</th>
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<td>(n = 17)</td>
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<td>1. Professional development</td>
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<td>100</td>
<td>US, CBS, ACS, CS</td>
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<td><strong>General recommendations</strong></td>
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<td>• an extended time frame</td>
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<td>94</td>
<td>US, CBS, ACS, CS</td>
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<td>• <strong>Utilitarian</strong></td>
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<td>• is grounded in the classroom;</td>
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<td>• provides alternative teaching strategies.</td>
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<td>• <strong>Content-Based Science</strong></td>
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<td>• provides step-by-step instruction;</td>
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<td>• uses a resource guide as training manual.</td>
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<td>• <strong>Authentic Contextual Science</strong></td>
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<td>• describes open-ended inquiry.</td>
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<td>• <strong>Citizenship Science</strong></td>
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<td>• provides active and direct experience;</td>
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<td>• provides alternative strategies;</td>
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<td>• teaches teachers to be mentors and facilitators;</td>
<td></td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>• develops confidence and inspires.</td>
<td></td>
<td>24</td>
<td></td>
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<tr>
<td>2. Mentors</td>
<td>--</td>
<td>88</td>
<td>US, CBS, ACS, CS</td>
</tr>
</tbody>
</table>
### 3. Teacher collaboration and cooperation

- release time for classroom visitations: 28% (47% for Stage 3); US, CBS, ACS, CS
- on-line communication: 14% (18% for Stage 3); US
- teachers-coaching-teachers: -- (41% for Stage 3); CS

### 4. Department funding

- special funding for student investigations: -- (41% for Stage 3); US, CBS, ACS, CS
- a central equipment depot: -- (35% for Stage 3); CS
- textbooks and other curriculum resources: -- (18% for Stage 3); CBS
- high speed Internet: -- (18% for Stage 3); US, ACS, CS

*Note.* US = Utilitarian Science; CBS = Content-Based Science; ACK = Authentic Contextual Science; CS = Citizenship Science
Open-Ended View of Inquiry (OEI)

**Quadrant 4 Citizenship Science**
*Preferred type of inquiry: Fully Open*
*Program support for teachers in general:*
  a) **Professional Development**
    *provides active and direct teacher experience;*
    *presents alternative strategies for implementation;*
    *teaches teachers to be facilitators and mentors;*
    *develops confidence and inspires teachers to enact open-ended inquiry.*
  b) Teachers-coaching teachers;
  c) A central equipment depot;
  d) High speed internet.

**Quadrant 1 Utilitarian Science**
*Preferred type of inquiry: Guided*
*Program Support for teachers in general:*
  a) **Professional Development**
    *is delivered by experienced experts;*
    *is grounded in the classroom;*
    *provides exemplars;*
    *provides alternative teaching strategies.*
  b) On-line communication;
  c) High speed internet.

**Quadrant 3 Authentic Contextual Science**
*Preferred type of inquiry: Structured*
*Personal Program Support:*
  a) **Professional Development**
    *describes open-ended inquiry and the stages of enactment;*
  b) High speed internet.

**Quadrant 2: Science as Knowledge**
*Preferred type of inquiry: Confirmation*
*Personal Program Support:*
  a) **Professional Development**
    *provides step-by-step instruction;*
    *uses a resource guidebook as a training manual;*
  b) Textbooks and other curriculum resources.

Closed-Ended View of Inquiry

**Figure 7.** Program support by stance related to enactment of open-ended inquiry

**Program support (all stances):**
- Professional Development (extended timeframe)
- Mentors (classroom, board)
- Teacher Collaboration and Cooperation (release time for classroom visitations)
- Funding of Science Program (targeted for student investigations)

**Figure 8.** Program support recommended for enactment of open-ended inquiry by participants from all stances.
In spite of a multi-decade mandate to enact inquiry in science that is open-ended and developmental in perspective, research reports that a large gap continues to exist between the goals of science education presented in curriculum documents and what is enacted in the classroom (Abd-El-Khalick et al., 2004; Barrow, 2006; Crawford, 2007; Yager, 2005). Here, recognizing that teaching and learning in relation to inquiry in science must change if current curricular goals are to be met, the purpose of this study was to explore inquiry teaching, specifically, the links between teachers’ reported beliefs and their reported practice related to inquiry (Cronin-Jones, 1991; Crawford, 2007), and to identify challenges and program support. In doing so, based on the literature, I developed a questionnaire that led to the development of a tentative framework illustrating the dimensionality of teachers’ beliefs and teaching practices related to inquiry as practical work in secondary school science.

Thematic analysis of interview data resulted in the characterization of four types of science teachers associated with four stance based on their reported beliefs and preferred teaching practices pertaining to inquiry. Comparing and then merging these characterizations with the beliefs profiles of my framework, confirmed and then expanded the framework to include the characterization of four types of science teachers corresponding to the four quadrants of the framework.

Huang (2006) argues that investigating science teachers’ perceptions of their teaching environment is an important starting point for identifying the current status of secondary school teaching environments in science and determining what teachers’ judge to be less satisfactory and in need of change. Responding to this position, my study explored factors that teachers reported as representing challenges to their implementation of open-ended types of inquiry. Finally, Krajcik et
al. (1994) maintained that past lessons confirm that, unless ways are found to identify and overcome challenges in teaching, open-ended types of inquiry may not be widely adopted and, therefore, this gap between the vision of science related to inquiry contained in curriculum documents and teaching practice in science will not be reduced. With the goal of providing some answers as to how these challenges to enactment could be addressed, teachers were asked to identify types of program support which they considered would foster the implementation of open-ended types of inquiry in science.

In this chapter, I discuss my framework illustrating the dimensionality of teachers’ reported beliefs about teaching and learning and teaching practices related to inquiry. I then discuss the characterizations of four types of science teachers identified in this study and present the stances developed to represent them. The first part of this chapter addresses my first two research questions. Lastly, I discuss the challenges identified by participants as impeding teachers’ enactment of open-ended inquiry and discuss the types of program support recommended by them to foster the implementation of open-ended inquiry in science thereby addressing research questions three and four.

**Teachers’ Beliefs and Enactment of Inquiry**

**A Framework to Illustrate Dimensionality**

A teachers’ reported beliefs measure was developed to explore teachers’ beliefs related to teaching and learning in inquiry based on the a priori assumption, supported by the literature, that teachers’ beliefs would be bi-dimensional with a knowledge-transmission view or orientation at one pole of a single axis and a learning-facilitation view or orientation at the opposite pole (Kember & Kwan, 2002). This pair of dimensions was viewed as a continuum. Research indicated that teachers
identified as holding a knowledge-transmission view of teaching and learning would emphasize a content-centred approach to teaching (Kember & Kwan, 2002) transmitting scientific knowledge as fixed, proven facts (Kember & Kwan, 2002; Trigwell, Prosser, Marton & Runesson, 2002). In comparison, teachers identified as holding a learning-facilitation view, or orientation, were reported to use learning-centred approaches with a teaching emphasis on facilitating student understanding, conceptual change and intellectual development (Hativa, 2002; Kember & Kwan, 2002).

However, analysis of survey data from the teachers’ reported beliefs measure revealed four dimensions as four clusters of coherent beliefs corresponding to four views, or orientations, including: a student-directed view of learning; a teacher-directed view of learning; an open-ended view of inquiry; and a closed-ended view of inquiry. Two of these clusters of beliefs corresponded very closely to my anticipated results including: (a) a teacher-directed view of learning with teachers reporting an emphasis on directing and controlling student learning and giving priority to transmitting knowledge; and (b) a student-directed view of learning with students being given some control over their learning and a teaching emphasis on facilitating understanding and development of critical thinking skills.

As indicated, two additional clusters of coherent teachers’ beliefs emerged during data analysis that corresponded to the degree of open-endedness of inquiry including: (a) an open-ended view of inquiry with teachers reporting an emphasis on student independence in inquiry as practical science; and (b) a closed-ended view of inquiry with teachers reporting an emphasis on directing and controlling student investigations.

The four clusters of teachers’ beliefs which emerged during quantitative analysis of survey data, suggested a relationship between teachers’ beliefs and teaching practices related to inquiry in science. This finding is supported in literature by Cronin-Jones (1991) and Fang (1996). During the
later stages of this investigation, facets of this relationship between teachers’ beliefs and teaching practices related to inquiry were explored through quantitative and qualitative analysis of data and the subsequent merging of both quantitative and qualitative findings. These will be discussed in more detail below.

**Characterizing Types of Teachers and Applying the Framework**

Four types of participants were identified during thematic analysis of interview data differentiated by their reported preference in teaching inquiry including: type 1 (confirmation inquiry); type 2 (structured inquiry); type 3 (guided inquiry); type 4 (fully open inquiry). A teachers’ beliefs profile, a stance, and a common theme were developed to represent each type of teacher. The stances developed included: utilitarian science (type 1); content-based science (type 2); authentic contextual science (type 3); and citizenship science (type 4). In this study, the four stances that emerged represent four overarching views of four types of science teachers differentiated with respect to teaching and learning and preferred teaching practices related to inquiry.

As reported in chapter 2 and mentioned earlier in this chapter, a broad base of literature indicates that teachers’ beliefs affect their teaching practices (Cronin-Jones, 1991; Fang, 1996; Hogan & Berkowitz, 2000; Parjares, 1992; Southerland et al., 2002, Stipek, Givven, Salmon & MacGyners, 2001). Findings in this study support this position and extend this influence of teachers’ beliefs on teaching practice to include inquiry. In regard to the Ministry’s goal of broad-based implementation of open-ended inquiry in science, perhaps Nicole summarized it most eloquently in stating: “If a teacher doesn’t believe that it’s a worthy approach, they’re not going to be engaged in it and they’re not going to be a part of it.”
More specifically, teachers regarded as holding a content-based science stance who communicated a teacher-directed, knowledge-transmission view of teaching and learning also reported teaching confirmation inquiry in science. Entwistle and Walker (2002) as well as Roth and Roychoudhury (2003) recognized a teacher-centred view of teaching and learning where the teaching emphasis is on controlling and managing student learning and priority is attached to teaching the content in the curriculum. A preference for confirmation inquiry as ‘recipe’ textbook labs is not unexpected for this group of teachers (content-based science) since this type of inquiry provides teachers with the opportunity to control both the investigative process and the investigative findings.

In comparison, science teachers categorized as holding a citizenship science stance communicated a student-directed, learning-facilitation view of teaching and learning related to inquiry with their curricular emphasis being identified as connecting learning in science to the lives and interests of their students and to real-life events and issues outside of the classroom. There is support in the literature for this view of science education (Abd-El-Khalick et al., 2004; National Research Council, 1996; Yager, 2005) and for the view that a teachers’ role includes guiding and mentoring student learning (Roth & Roychoudhury, 2003; National Research Council, 1996; Luehmann, 2007) in a collaborative learning environment (National Research Council, 2000). Additionally, these teachers identified an emphasis on developing a knowledge base and skill set to support critical thinking which provides students with opportunities to carry out scientific practices somewhat similar to those of real scientists. The National Research Council (1996, 2000) offers strong support for this emphasis in science education.

Furthermore, it is not surprising that teachers holding beliefs about science teaching as knowledge-transmission (a content-based science stance) communicate a preference for closed-
ended inquiry. Conversely, it is not surprising that teachers, who view science teaching as facilitating learning, would communicate a preference for open-ended inquiry. However, it should be noted that the findings of this study also indicate that teachers shift their teaching of inquiry to achieve different educational goals. Therefore, these stances represent an emphasis for an individual and are not mutually exclusive. For example, teachers identified as holding a citizenship science stance reported that, in addition to the enactment of fully open inquiry (a type of open-ended inquiry), they also teach confirmation inquiry (a type of closed-ended inquiry) for the purpose of developing specific skills of inquiry which their students later apply during engagement in fully open inquiry. This was similarly true for teachers associated with a utilitarian stance who reported that they also teach confirmation inquiry for the purpose of skill development to support students’ later engagement in guided inquiry. While the coupling of these two types of open-ended inquiry (fully open and guided inquiry) with confirmation inquiry (a closed-ended type of inquiry) are not well covered in the literature, a type of coupled inquiry that connects fully open inquiry with guided inquiry is reported by Martin-Hansen (2002). In this latter approach to coupled inquiry, guided inquiry is being used for the purpose of training students in specific skills of inquiry for later application in open-ended inquiry (Martin-Hansen, 2002).

Science teachers associated with three stances (content-based science, authentic contextual science and utilitarian science) in this study reported readiness to shift orientation. This finding has been less reported in the literature. The majority of teachers associated with a content-based science stance, who reported a preference for teaching confirmation inquiry (viewed as a closed-ended type of inquiry) communicated a readiness, with resource support, to teach structured inquiry. Structured inquiry is also viewed as a closed-ended type of inquiry but one which incorporates a more student-directed approach to inquiry. This group of science teachers (content-based science) indicated that
they were interested in incorporating some science content in their classes that would be more personally meaningful to students and doing so through structured inquiry. In addition, science teachers associated with an authentic contextual science stance who reported a preference for teaching structured inquiry (a closed-ended type of inquiry), indicated a willingness, with resource support, to enact guided inquiry (an open-ended type of inquiry). Chemistry or physics challenges were identified where they would select a topic for student investigation which they judged to be meaningful to their students. Resource materials in the form of ideas for investigation, web sites, rubrics and other assessment tools were identified as a necessary support for this shift in teaching inquiry.

Lastly, all of the teachers associated with utilitarian science reported a teaching preference for guided inquiry. However, within this group of teachers 50% identified a readiness to begin the process of learning how to enact fully open inquiry now if they are provided with mentor support. A lack of pedagogical content knowledge was identified as a major impediment to their shift in orientation. Mentors, with demonstrated expertise in enacting fully open inquiry, were recommended by them as representing the greatest potential for bridging their knowledge-practice gap.

It should be noted that what I present here with respect to four types of science teachers, their associated beliefs profiles and their associated stances, are teachers’ reported predominant over-riding emphases with regard to teaching and learning related to inquiry. What also emerges is the complexity of the field with different types of inquiry being used to achieve different purposes; the coupling of different types of inquiry being used to scaffold student development; and the declared readiness of teachers to shift teaching emphases from more closed-ended to more open-ended types of inquiry. The direction of this preparedness to shift was identified as being from confirmation to
structured inquiry with resource support; from structured inquiry to guided inquiry with resource support; and finally, from guided inquiry to fully open inquiry with mentor support.

**Closing the Inquiry Gap: Challenges and Program Support**

While curriculum documents require the implementation of open-ended types of inquiry (guided and fully open inquiry) as practical science (National Research Council, 2000), teaching practice is reported to consist of largely, closed-ended types of inquiry (confirmation and structured inquiry) (Abd-El-Khalick et al., 2004; Hofstein & Lunetta, 2004; Windschitl, 2002; Yager, 2005). The majority of the interviewees in this study supported the literature reporting that closed-ended inquiry is the most common approach to teaching inquiry in their science departments. Research indicates that teachers can teach open-ended inquiry (Anderson, 2002; Blumenfeld et al., 1991; Windschitl, 2006) but that this shift in emphasis to open-ended types of inquiry is difficult to achieve (Anderson & Helms, 2001; Blumenfeld et al., 1991). The majority of participants in this study agree.

With the goal of finding ways to support teachers’ implementation of open-ended inquiry, participants were first asked to identify and describe challenges that significantly impede the enactment of open-ended inquiry and, then, asked to recommend types of program support that would foster enactment of open-ended types of inquiry. In doing so, this study has responded to the position of Krajcik et al. (1994) who state that: “Attention needs to needs paid to ways of supporting teachers; otherwise, innovation will not be successful” (p. 484).

While some challenges to implementation of open-ended inquiry and recommendations for program support were identified by interviewees associated with specific stances (see Figures 5 and 7, p. 112, 139), other challenges and recommendations for program support were more generally identified by survey respondents and interviewees associated with all stances (see Figures 6 and 8,
p. 112 and 139). I will discuss the challenges to enactment of open-ended inquiry and recommendations for program support reported by teachers in this study from both a broader perspective (the collective view of participants associated with all stances) and a narrower perspective (the particular views of participants associated with specific stances).

The findings of this study support the position that different types of science teachers exist who have different views and needs. To foster a broader base of enactment of open-ended inquiry, educational leaders and teacher-educators (pre-service and in-service) must consider not only the views and needs of science teachers in general but also, must to consider the more specific of views and needs of different types of teachers all of whom are expected to implement open-ended inquiry as practical science.

**Challenges to Enactment of Open-Ended Inquiry**

**Personal Challenges**

Participants in this study, representing 80 percent of the target population, and interviewees identified both personal and contextual challenges (Krajcik et al., 1994) that they regarded as significantly impeding the enactment of open-ended inquiry. Personal challenges reported by these teachers included: a lack of knowledge about what open-ended inquiry is and what it would look like in the classroom; teachers’ need to control and manage student learning and behaviour; teachers’ accountability to teach the whole curriculum which they view as being content-loaded and restrictive; time investment in course plans; and teachers’ general resistance to change.

Krajcik et al. (1994) and Blumenfeld et al. (1991) recognized teachers’ lack of knowledge as a challenge to the implementation of open-ended types of inquiry. Although teachers might have the content knowledge to support teaching inquiry, Blumenfeld et al. (1991) maintained that teachers
often lack the pedagogical content knowledge related to initiating and managing open-ended types of inquiry in the classroom and to scaffolding students’ investigative skills of inquiry. Two groups of teachers in this study (content-based science and authentic contextual science), both of whom reported that they do not enact open-ended inquiry, clearly identified a general lack of knowledge and corresponding lowered self-efficacy related to the implementation of open-ended types of inquiry. Not only did they express a lack of confidence in being able to introduce open-ended inquiry to their students but also reported a lack of confidence in being able to manage an open-ended inquiry-based classroom such that target goals for student learning would be successfully achieved.

With respect to knowledge about inquiry, participants considered as holding a content-based science stance, reported that teaching open-ended inquiry was not part of their teacher education program and that this lack of training had contributed, in a major way, to their lack of interest in implementing this type of inquiry as they began their teaching career and has contributed to their continued resistance to do so now (Luehmann, 2007; Windschitl, 2002). Wee et al. (2007) also recognized this as a problem in science education. Additionally, Crawford (2007) identified pre-service teachers’ beliefs about teaching and view of science as critical factors influencing teachers’ intention and perceived ability to teach open-ended inquiry.

Brickhouse and Bodner (1992) acknowledged the importance of teacher education in helping teachers both: “develop a rationale for teaching science but also provide ways of actually accomplishing this in the classroom” (p. 482). This should include the enactment of open-ended types of inquiry as practical science. Several science teachers in this study reported that the content-oriented training which they received in teachers’ college had contributed, in a major way, to their current teaching approach and curricular priorities as it reinforced their own school experiences.
However in spite of reports by all participants that open-ended types of inquiry were not part of their teacher-training program, it is interesting to note that almost all of the interviewees reported personal experience as students with open-ended inquiry as fully open or guided inquiry. This finding was surprising and contrary to what is reported in the literature (Abd-El-Khalick et al., 2004; Crawford, 1999; Lotter, Harwood & Bonner, 2006; Luehmann, 2007; Windschitl, 2002; Yager, 2005). Abd-El-Khalick et al. (2004) maintain that the majority of science teachers have no personal experience with open-ended inquiry. Furthermore, each of these participants reported that their earlier experience(s) with open-ended inquiry had been enjoyable and long-lasting so much so that they could recall (in some cases with great detail) how much they had learned during these experience(s) (see Appendix Table F6 for personal reflections of interviewees) in spite of the passage of time. Otherwise, these participants could report only vague general memories of science learned at the same time.

Although research reported that teachers’ personal experience, as a students, ‘doing’ open-ended inquiry influences their teaching practice in relation to the enactment of open-ended inquiry (Eick & Reed, 2002; Windschitl, 2002), this was not the case for four teachers associated with two stances (content-based science and authentic contextual science). Confirming personal experience doing open-ended inquiry as students, with this experience occurring at the university level for two of them, these four participants reported that they do not enact open-ended inquiry as teachers. However, this was the case for the remaining two stances (citizenship science and utilitarian science). All participants associated with these two stances reported that their experience of ‘doing’ open-ended inquiry, as students, was one of the contributing factors to their decision to implement open-ended inquiry in their own science classes. As was true in my case, a participant considered as
holding a citizenship science stance, reported that his personal experience of doing open-ended inquiry as a student has framed the way he teaches science.

The view of curriculum documents in science as being content heavy and very restrictive was identified generally by teachers associated with all stances. While teachers associated with two stances (utilitarian science, citizenship science) reported these challenges from the perspective of their colleagues implementation of open-ended inquiry, teachers associated with authentic contextual science and content-based science identify these challenges to their own enactment of open-ended inquiry. Martin (2003) and Minner et al. (2010) report these challenges. Teachers associated with content-based science, in addition to reporting the view that current curriculum documents are content heavy, communicated the view that the ministry holds them accountable to teach this curriculum content thereby impeding their enactment of open-ended types of inquiry. Blumenfeld et al. (1991) identified teachers’ beliefs about the goals for science education and their role with respect to these goals as deterrents to implementation of open-ended types of inquiry.

The constraining influence of a teacher’s belief that she/he must cover the course content in the curriculum is also addressed by Abd-El-Khalick et al. (2004), who indicated that teachers holding this belief consider the extra time required to incorporate students ‘doing’ open-ended types of inquiry as inefficient and therefore, ineffective. In my study, teachers associated with a content-based science stance certainly communicated this position. In addition, the comments of teachers associated with a content-based science stance clearly indicated that the four ‘cultural myth’s (transmission, rigor, efficiency and preparing students for examination) identified by Tobin and McRobbie (1996) were strongly influencing their reported curricular decision-making. In reflecting these four ‘myths’, participants communicated a knowledge-transmission view of teaching and learning related to inquiry with teaching priority given to controlling and managing student learning
and behaviour. However, their expressed concern about efficiency and effectiveness in covering the prescribed curriculum was linked to the importance which they attach to preparing their students for the next level of study in science rather than specifically preparing them for the final exam.

Additionally, teachers from each identified group confirmed research indicating that many teachers actively resist teaching open-ended types of inquiry (Cronin-Jones, 1991; Keys & Kennedy, 1999; Kleine et al., 2002). While teachers considered as holding a utilitarian science stance and a citizenship science stance reported this resistance as being communicated by their colleagues, teachers associated with an authentic contextual science stance and a content-based science stance discussed their own resistance to teaching open-ended inquiry. Keys and Kennedy (1999) state: “Past studies have indicated that, when inquiry-oriented curriculum is imposed on teachers by well-meaning researchers or school personnel, teachers resist full implementation, shaping instruction to match their own beliefs about teaching and learning” (p. 316).

This trend was particularly evident in the expressed view of teachers considered as holding a content-based science stance. In discussing their plans for implementing the new curriculum (Ministry of Education, 2008), some teachers confirmed that their resistance to enacting open-ended inquiry would continue unless and until their need for program support has been met. This is consistent with a report by Krajcik et al. (1994). In discussing their need for program support, being provided with knowledge (content knowledge, pedagogical knowledge and pedagogical content knowledge) to fully support the implementation of open-ended inquiry, was identified as a very high priority which these teachers suggested should be delivered as professional development. Furthermore, they maintained that such professional development should be followed by support in the form of a classroom-based mentor; a resource guide specific to open-ended inquiry; and a textbook incorporating an open-ended approach to inquiry.
Several other factors were identified by interviewees as contributing to teachers’ resistance to teaching open-ended types of inquiry including: teachers’ desire to control and manage students’ learning and behavior (content-based science); their view of open-ended inquiry as “extra” practical work in science (content-based science); teachers’ reticence to change their course plans (content-based science and authentic contextual science); and their perception that curricular change has been and will continue to be on-going (utilitarian science; content-based science; authentic contextual science; citizenship science). Teachers’ desire for control and management of student learning and behavior is documented in the literature. This is not found to be the case for the other challenges to enactment identified as significant by teachers in this study. Entwistle and Walker (2002) associated a teachers’ emphasis on control and management of student learning and behavior with a knowledge-transmission orientation to teaching which is teacher-centered and content-oriented. The findings in this study confirm this relationship. Participants regarded as holding a content-based science stance, who communicated a teacher-directed view of teaching and learning related to inquiry, were the teachers who reported an emphasis on control and management of student learning and behavior. Co-incidentally, these teachers also reported a closed-ended view of inquiry.

Teachers in this same group (content-based science) also communicated that, according to their interpretation of curriculum, open-ended inquiry is not specifically indicated and, therefore, they regard open-ended inquiry as extra practical work. As a result, they would like the ministry to more clearly define its curricular expectations with regard to teaching open-ended inquiry and the nature of science. A lack of specificity by curriculum leaders was implicit in Windschitl’s (2002) report of teacher confusion about inquiry. Wee et al. (2007) also reported confusion among teachers in relation to the nature of open-ended inquiry and what it might look like in the classroom. Such a lack of specificity in curriculum documents about when, why, and how open-ended inquiry could or
should be implemented in the science curriculum may be a very significant, contributing factor to teachers’ resistance to enacting open-ended inquiry. In the goal of fostering teachers’ implementation of open-ended inquiry, the ministry needs to pay more specific attention to the way that inquiry is defined and how it is portrayed in curriculum documents.

Lastly, teachers’ generally reported the view that there has been too much curricular change both directly and indirectly related to science. The problem of continual curricular change in education is also reported in the literature (Melville, 2008). Melville (2008) states: “The scale of these changes can vary from mandated systematic curriculum changes to demands in schools by the local community” (p. 1185). Many participants associated with each stance confirmed that, during the past few years, curricular change has been on-going with concurrent implementation, in some cases, of multiple change initiatives (and often contradictory). For several of these participants, the ministry’s latest curricular documents (Ministry of Education, 2008) represent just the latest mandate for science education and not the last.

**Contextual Challenges**

Contextual challenges are regarded as those that are external to the teacher and are beyond the control of the teacher (Krajcik et al., 1994). Krajcik et al. (1994) identified these challenges as originating in the classroom, the school, or the district. Some participants in this study also identified challenges that originated in the ministry such as decisions related to the teaching of inquiry. The contextual challenges identified were reported to directly or indirectly influence how a teacher implements open-ended inquiry or conversely, to influence a teachers’ decision not to enact open-ended inquiry.
In this research, these changes were identified as: department funding, student interest and motivation to learn science, teachers’ workload, class size and safety, time in the semester, and a lack of time for teacher collaboration were identified as significant challenges to the implementation of open-ended inquiry. Most of these challenges have been broadly reported in the literature (Abd-El-Khalick et al., 2004; Anderson & Helms, 2001; Blumenfeld et al., 1991; Brickhouse & Bodner, 1992; Brown & Melear, 2006; Edelson, Gordon, & Pea, 1999; Hogon & Berkowitz, 2000; Huang, 2006; Keys & Kennedy, 1999; Krajcik et al., 1994; Lotter, Harwood, & Bonner, 2006; Marx et al., 1994; Posnaski, 2002; Songer et al., 2002; Zhang et al., 2004). The restriction on time available for teaching and learning in science which is associated with a semestered school year has not been so widely reported in the literature. This challenge was identified by most of the survey respondents and confirmed, during semi-structured interviews, by a large majority of the participants. Interviewees considered the semester system to represent a highly significant deterrent to the enactment of open-ended inquiry for teachers not currently teaching this type of inquiry. Poor transfer of learning from one science course to the next and a lack of time for skill development were identified as two problems generally associated with the semester system. The broad report of this challenge to the implementation of open-ended inquiry suggests that it should be a challenge of interest to administrators and the ministry.

Although funding of science education was documented in the literature (Anderson, 2002; Barrow, 2006; Haberman, 1991; Krajcik et al., 1994; Wee et al., 2007; Welch et al., 1981; Zhang et al., 2003), it was not accorded the level of importance to the implementation of inquiry reported by almost all participants in this study. These teachers regarded the critical lack of funding currently being experienced in science to be seriously limiting to present as well as future implementation of open-ended inquiry. Huang (2006) recognized the importance of the educational environment to
teacher morale and teaching practice. There was evidence in this study that the continual lack of equipment and resources available for practical science was contributing to lowered teacher morale.

Although class size is more often linked to control and management issues in the literature (Keys & Kennedy, 1999), reports by these participants do not do bear this out. Instead, they linked class size to safety issues maintaining that, unless attention is paid to limiting the size of classes in science, teachers will not begin to implement open-ended types of inquiry and many of those who do so now may not be able to continue to do so. Open-ended inquiry often means that students are doing different experiments in a science lab at the same time and, in most cases, are doing so without specific step-by-step instruction. Also, open-ended inquiry means that a teacher may be facilitating students in several groups where each group may be working at a different stage in the investigative process. Moreover, in fully open inquiry, teachers are facilitating groups of students who are investigating different topics. Under these conditions, the larger the class, the more difficult it is for a teacher to pay close attention to safety. Teachers’ description of their battle to teach science with success in large classes (32-36 students) was reminiscent of Haberman’s (1991) description of the “pedagogy of poverty” (p. 290).

Program Support for Enactment of Open-Ended Inquiry

Four primary types of program support were recommended as meaningful to the implementation of open-ended inquiry: professional development, mentors, teacher collaboration, and funding. Each of these is discussed below.

Professional Development: Closing the Knowledge Gap

The majority of participants in this study recognized the importance of providing teachers with a knowledge base to support enactment of open-ended inquiry. As discussed earlier, this was a
particular concern for teachers associated with two stances (content-based science and authentic contextual science) who reported that, to date, they have not implemented open-ended inquiry as practical science.

Additionally, interviewees generally (all stances) recommended that professional development be delivered over an extended timeframe. Research provides support for this position (National Research Council, 1996; Garet et al., 2001; Melville & Bartley, 2010). For teachers considered as holding a content-based science stance, a one-week summer institute was recommended. A one-week timeframe was identified by these teachers as providing sufficient time to increase content knowledge and pedagogical content knowledge and give them time to gain the confidence necessary to implement open-ended types of inquiry for the first time. Lotter et al. (2006) confirmed that a summer institute (2 weeks in length) had been successful in increasing teachers’ knowledge and level of confidence resulting in their reported increased ability to use inquiry-based teaching practices in their classrooms. Based on this research, it is recommended that a summer institute incorporating a two-week timeframe be considered. Lotter et al. (2006) advise that: “Teachers need time to practice, reflect on, and revise innovative techniques in supportive, collaborative, and real classroom environments” (p. 186).

Similarly, Loucks-Horsely and Matsumoto (1999) reported that professional development in an extended timeframe also provides opportunities to discuss problems related to practice and to receive feedback on new teaching strategies and their possible application. A summer institute should provide time for practice, reflection and revision of ideas and resources. Loucks-Horsley and Matsumoto (1999) maintained that “opportunities for analysis and reflection” (p. 262) are important to learning to enact open-ended inquiry. The importance of creating a learning environment that is collaborative and cooperative to build teachers’ self-efficacy beliefs is emphasized by Lotter et al.
With an extended timeframe and the relaxed atmosphere associated with this time of the year, a summer institute would make establishing a collaborative, cooperative and reflective learning environment much more achievable.

For all other groups of participants, the recommended extended timeframe for professional development ranged from two to five days. Professional development, delivered over such an extended timeframe, was identified in the literature as successfully leading to knowledge building to support improved student learning (Anderson, Holland, & Palincsar, 1997; Krajcik et al., 1994). The participants in this study stressed the importance of professional development providing a way for teachers from different schools to connect with one another and form collaborative teams which could support one another following professional development. Such teams of teachers, working together and supporting one another, were also reported as important to teacher success during and following any training (Posnanski, 2002).

In agreement, Krajcik et al. (1994) states that: “teachers construct knowledge through social interaction with peers applying ideas in practice and through reflection” (p. 490). Professional development, delivered over an extended timeframe during the school year, should provide an opportunity for social interaction in which teachers would have the chance to share their ideas, their successes and the sources of their disappointments as they are learning about how to enact open-ended types of inquiry.

_Types of Professional Development Recommended by Stance_

As discussed earlier, four different stances were identified in this study differentiated by their expressed beliefs about teaching and learning and teaching practices related to inquiry. As would be expected, given the differences in beliefs and teaching practices reported in association with each of these four stances, differences were also found in the specific recommendations made by each group
regarding professional development to facilitate the enactment of open-ended types of inquiry. Successful professional development to foster the broad-based implementation of open-ended inquiry would expect to meet the needs of many different types of science teachers including each of the four types identified in this study. For this reason, specific recommendations of each type of teacher and the audience which they target become important.

**Utilitarian Science**

Teachers regarded as holding a utilitarian science stance made suggestions for professional development designed to foster implementation of open-ended types of inquiry by teachers who do not currently teach these types of inquiry. Their recommendations included professional development that: is grounded in the classroom; is delivered by an experienced expert; provides exemplars; and provides alternative teaching strategies related to enactment of open-ended inquiry.

In recommending professional development that is delivered by an experienced expert who can provide alternative strategies to balance teaching science as content and science as process and can teach scaffolding of the skills of inquiry, teachers are calling for a professional development leader who has a high level of pedagogical content knowledge (Shulman, 1986). According to this group of participants, it is most important to provide teachers with knowledge (content and skills) which is critical to their enactment of open-ended inquiry followed by instruction on how to teach this knowledge to students by an instructor who has direct classroom experience and demonstrated expertise in this area. Additionally, these participants recommended that such professional development should be supported by exemplars to model excellence in aspects of enactment. Some support can be found in the literature for these recommendations (Bell et al., 2003; Loucks-Horsley & Matsumoto, 1999; Marx et al., 1994; Yager, 2005).
With its emphasis on scaffolding the development of students’ skills of inquiry and the provision for teaching alternative strategies to balance teaching science as content and science as process, this recommended professional development could build teachers’ content knowledge and pedagogical knowledge which is, also, linked in research to building teachers’ self-efficacy beliefs (Posnanski, 2002).

**Content-Based Science**

According to participants regarded as holding a content-based science stance, professional development to facilitate their own enactment of open-ended inquiry needs to be delivered with a step-by-step approach to instruction. They also identified a need for a resource guidebook which is used as a training manual during professional development and later can provide curricular support as they begin to implement open-ended inquiry in the classroom. Anderson (2002) indicated that teachers focus their attention on what works in the classroom in relation to student engagement and classroom management and stated: “Teachers’ view of teaching is dominated by tasks and activities” (p. 9). In discussions pertaining to professional development in support of enactment of open-ended inquiry, the focus of these science teachers was clearly on practical matters.

Included in their discussions was the report that they would like to participate in professional development that is specifically designed to increase their knowledge (content and pedagogical knowledge) by incorporating a ‘step-by-step’, ‘black-and-white’ approach to instruction on methods related to all aspects of enactment. Lotter et al. (2006) indicated support for such a systematic approach to learning specific methods, in this case related to the enactment of open-ended inquiry, maintaining that it is important to break down the problem of implementation into smaller more manageable steps.
Van den Berg (2002) reported, as did several of the teachers in this study, that teachers want to feel competent in what they do. Teachers regarded as holding a content-based science stance clearly indicated that they want to ‘feel’ a sense of competency before they will consider implementing open-ended types of inquiry in their classrooms. The type of professional development proposed by this group of teachers should be successful in increasing their content knowledge and pedagogical knowledge related to enacting open-ended inquiry and thereby increase their self-efficacy beliefs. Posnanski (2002) supports this position.

**Authentic Contextual Science**

Professional development that generally describes the nature of and methods of teaching open-ended types of inquiry was recommended by teachers reflecting an authentic contextual science stance. As was the case for teachers considered as holding a content-based science stance, this proposal for professional development was reported as a call for knowledge (content knowledge and pedagogical knowledge) which would remove at least some of the uncertainty and confusion identified by these participants in relation to open-ended inquiry. As indicated earlier, Wee et al. (2007) reported confusion among teachers about the nature of open-ended inquiry and what it might look like in the classroom.

**Citizenship Science**

Lastly, participants regarded as holding a citizenship science stance (who reported teaching fully open inquiry) recommended approaches to professional development that were aimed at teachers who are learning how to enact open-ended inquiry. Their suggestions included professional development that: provides direct and active experience for teachers by having them assume the role of students and ‘do’ open-ended inquiry; provides alternative strategies to network on behalf of
students; teaches teachers to be mentors and facilitators; and develops confidence and inspires teachers to implement open-ended types of inquiry in their classrooms.

Research supports their recommendation for a more constructivist “hands-on, minds-on” (Anderson, 2002; Garet et al., 2001; Melville, 2008; Posnanski, 2002) approach to professional development and indicates that such an approach would contribute significantly to reducing confusion related to the implementation of open-ended inquiry (Melville & Bartley, 2010; Wee et al., 2007; Windschitl, 2006). In addition, having the opportunity to learn about teaching open-ended inquiry by ‘doing’ open-ended inquiry would contribute to developing awareness that the role of a teacher during open-ended inquiry becomes that of facilitator and mentor. This position is supported by Crawford (2007).

Research reports that teachers who participated in professional development programs involving them as active learners successfully constructed knowledge and skills (Bell et al., 2003; Garet et al., 2001; Loucks-Horsley & Matsumoto, 1999). Additionally, this type of experiential professional development should provide teachers with some alternative teaching strategies which were reported in research as important to sustained enactment of open-ended inquiry (Loucks-Horsley & Matsumoto, 1999). Also, in addition to contributing to increasing teachers’ content and pedagogical knowledge, this type of professional development would be expected to facilitate the development of teachers’ pedagogical content knowledge (Posnaski, 2002). Each of these three types of knowledge was reported as being significantly involved in teacher decision-making and teaching behavior (Nespor, 1987; Ormond & Cole, 1996).

Friedrichsen and Dana (2005) maintained that, in effective professional development, pedagogical content knowledge must successfully connect a teacher’s content knowledge with his/her pedagogical knowledge. Providing time for teacher reflection was identified as important to
building this kind of connection for teachers who are learning how to teach open-ended types of inquiry as practical work (Loucks-Horsley & Matsumoto, 1999). Krajcik et al. (1994) maintain that: “Experience educates via reflection” (p. 493). Participants in this group (citizenship science) emphasized the importance providing adequate time for teacher reflection and feedback during professional development designed to facilitate the enactment of open-ended inquiry.

Lastly, professional development, which emphasizes building knowledge through active learning, is reported by Banilower et al. (2007) as contributing to an increase in teachers’ self-efficacy and with this, according to participants in this group (citizenship science), teachers will have the confidence and the motivation to enact open-ended inquiry. A lack of knowledge and a corresponding lack of confidence in their ability to teach open-ended types of inquiry was consistently communicated by teachers holding a content-based science stance who reported that they do not teach open-ended types of inquiry.

Research indicates that teachers’ beliefs are important to teacher change (Anderson, 2002) and that changes in belief precede changes in teacher practice (Zhang et al., 2004). As was the case in the recommendation for a summer institute dedicated to open-ended types of inquiry, professional development, which incorporates opportunities for teachers to learn about enacting open-ended inquiry by ‘doing’ open-ended inquiry, especially in an extended timeframe, should contribute to changing teachers’ beliefs related to open-ended inquiry (Songer et al., 2002; Van den Berg, 2002) including the belief that enacting open-ended inquiry is difficult to achieve.

**Supporting Enactment of Open-Ended Inquiry: Mentors**

Providing support for teachers in the form of classroom-based, department-based and board-based mentors following professional development was recommended by interviewees associated with each stance. As recommended, a classroom-based mentor was viewed as providing
personalized, “direct job-embedded learning” (Loucks-Horsley & Matsumoto, 1999, p. 262) which could include modeling of some different elements of open-ended inquiry. Some participants from all groups (utilitarian science; content-based science; authentic contextual science; citizenship science) strongly favoured classroom mentors as a means of sustaining teachers’ enactment of open-ended inquiry. The potential of mentoring to foster the implementation of open-ended inquiry is supported in the literature (Melville & Bartley, 2010).

Bell et al. (2003) also provided support for this view reporting that the modeling of teaching techniques is effective as a means of increasing teachers’ knowledge of open-ended inquiry and contributes to teachers’ greater understanding of the elements of inquiry important to enactment of open-ended inquiry. Loucks-Horsely (2003) maintained that providing support for a teacher’s learning with direct feedback was a key to changing teaching practice which must link new conceptions of instructional practice to assessment of student learning. In addition, Lotter et al. (2006) identified mentors as effectively contributing to building a community of change in a school. This should also be true at the department level of a school if a classroom-based mentor is providing support to several teachers in the same science department.

Board-based mentors were viewed by participants as connecting with teachers, through electronic means, to provide on-going, ‘arms-length’ support from an expert for teachers who are actively teaching open-ended types of inquiry. Lotter et al. (2006) reported that coaching by an expert was effective in helping teachers to adapt curriculum to their students’ needs. Haberman (1995) drew attention to the importance of providing teachers with time to ‘tinker’ with aspects of their teaching practice. In this study, several teachers (content-based science, authentic contextual science), clearly communicated their desire for continued support during the ‘tinkering’ stage of learning how to enact open-ended inquiry. On-going support from a classroom-based mentor, a
department-based mentor and/or a board-based mentor could prove to be a highly effective as a strategy in the goal of facilitating and then sustaining enactment of open-ended inquiry.

**Facilitating Teacher Collaboration**

Participants in this study also identified on-going teacher collaboration and sharing as being very important to fostering sustained enactment of open-ended inquiry. This is to be expected since teachers had reported the lack of opportunity to collaborate with colleagues, particularly those in other schools, as contributing to a sense of isolation among teachers. Anderson (2002) and Anderson and Helms (2001) identified the importance of teacher collaboration with peers as a basis for resolving, albeit sometimes with difficulty, challenges to enactment of inquiry. Anderson (2002) states: “New understandings develop and new classroom practices emerge in the context of teachers’ collaboration with peers and experts” (p. 9) and adds: “Collaboration is a powerful stimulus for the reflection which is fundamental to changing beliefs, values, and understandings” (p. 9). Many teachers indicated that there is very little time for collaboration within their science departments during the school day, at the present time, and that there is almost no opportunity to collaborate with science teachers from other schools. Survey respondents and interviewees indicated that they would like to see a change in this situation.

Classroom visitations, on-line communication and a teachers-coaching-teachers initiative were presented as suggestions to foster teacher collaboration. Building communities of learning through strategies such as classroom visitations and on-line communication are reported in the literature as being an effective way of building teachers’ confidence and self-efficacy (Lotter et al., 2006; Melville & Bartley, 2010; Van den Berg, 2006) and sustaining them during enactment (Blumenfeld et al., 2000; Lotter et al., 2006; Loucks-Horsley & Matsumoto, 1999).
On-line types of communication (as seminars and demonstrations by a teacher modeling different elements of teaching open-ended inquiry) were recommended by participants regarded as holding a utilitarian science stance to provide long-term instruction on an as-needs basis to support teachers who are preparing to or are already implementing open-ended types of inquiry. Posnanski, (2002) reported that long-term training was important to teachers’ development. Participants reported that a great benefit of on-line seminars and demonstrations was that teachers have the opportunity to access information on their own time and at their own pace. Bell et al. (2003) suggested that the modeling of teaching techniques is effective at increasing teachers’ knowledge of open-ended inquiry by contributing to a teacher’s greater understanding of specific elements that are important to implementing open-ended types of inquiry.

A teachers-coaching-teachers initiative was recommended by teachers associated with citizenship science as a strategy to support the building of small communities of learning that would partner teachers according to their needs and expertise. Melville and Wallace (2007) suggest that the department structure would provide a context in which teachers could build a community of learning with teachers sharing experiences and learning from one another. While some participants in this study identified the department structure as one within which a teachers-coaching-teachers initiative could be initiated, others viewed such an initiative as being implemented across Pine Valley School Board with teachers in different schools coaching one another supported by video conferencing. In all cases, a teachers-coaching-teachers initiative was viewed as a strategy whereby teachers with demonstrated expertise could coach and mentor colleagues inexperienced in teaching open-ended inquiry.

Mundry (2005) recommends such a strategy for novice teachers to provide opportunities for them “to collaborate with others, reflect on practice, learn from data and results and see what does
and does not work in their classrooms” (p. 11). Loucks-Horsley and Matsumoto (1999) confirm that such communities of learning provide teachers with continued support and a means of addressing issues and solving problems as they surface during enactment. Participants, who suggested a teachers-coaching-teachers strategy to support teacher collaboration and sharing (a citizenship science stance), viewed this initiative as providing teachers with long-term support following professional development with the potential to contribute to building a spirit of change in their science teaching community. This continued support for teachers’ development in technique would be effective at increasing teacher knowledge of open-ended inquiry by contributing to a teachers’ greater understanding of elements of inquiry that are important to enactment (Melville & Bartley, 2009). Research (Garet et al., 2001; Melville & Bartley, 2010) indicates that long term support may be required. While Van den Berg (2002) reported that teachers begin to demonstrate higher levels of self-efficacy after two years of intensive support, Marx et al. (1997) and Blumenfeld et al. (1994) reported that almost three years was needed for teachers to grasp the ideas underlying project-based science (a type of open-ended inquiry).

Teachers, in this study, expressed great confidence in the potential of each of these types of long-term support to overcome teachers’ resistance to implementing open-ended inquiry and sustain them through the reported difficult early stages of enactment (Van den Berg, 2002) thereby increasing the likelihood of fostering sustained enactment of open-ended inquiry in science.

Supporting Enactment Through Funding

Science teachers generally reported that contextual support in the form of funding at the department level was critically needed to foster enactment of all types of inquiry but particularly open-ended types of inquiry. In this regard, teachers indicated that students doing open-ended investigations would add to the already highly constrained department budgets with which they are
dealing. Although funding in science has been identified generally in research as a challenge to enactment of open-ended inquiry (Brown et al., 2006; Brickhouse & Bodner, 1992; Keys & Kennedy, 1999; Krajcik et al., 1994; Marx et al., 1997), most of the participants in this study identified funding as a major barrier to the enactment of open-ended inquiry indicating that, if it is not solved, may continue to constrain enactment of open-ended inquiry even after professional development has filled any gap in knowledge.

The cost of science equipment and supplies were reported by many of these participants as being expensive with costs increasing each year such that current budgets are not keeping pace with current demands in science. This situation was acknowledged as contributing to lowered teacher morale and a steady increase in the incidence of teacher demonstrations replacing ‘recipe’ labs in science. However, although added funding could restore the availability of equipment and supplies to support the re-introduction of confirmation inquiry, it is not expected that funding alone will foster a shift to enactment of open-ended types of inquiry especially in the case of teachers who hold a knowledge transmission view of inquiry (content-based science). These teachers, who communicate a teacher-directed and content-centred orientation toward teaching and learning science are not likely to shift without opportunities to deeply reflect on their views and practices; direction from the ministry; and delivery of meaningful professional development to support a shift to a learning-facilitation model of teaching and learning in science.

In addition to funding for the purpose of updating and upgrading equipment, supplies, and computer technology in support of student investigations, interviewees made some specific recommendations for other types of funding. While teachers communicating a citizenship science stance recommended a centralized equipment depot to meet the specialized technological needs of some student projects, textbooks and other curriculum resources were identified as an important area
for funding by all participants considered as holding a content-based science stance. In comparison, teachers associated with three stances (citizenship science, utilitarian science, and authentic contextual science) recommended that funding be provided for high speed internet including the right to access scientific data bases to provide teachers and students with the opportunity to reference scientific articles. These additional specific areas of funding were not as well covered in the literature.

In summary, Crawford (2007) maintains that: “it is important to examine a teachers’ conception (view) of inquiry” (p. 637) but argues that such studies must include the teacher’s context of practice. This study has included examination of teachers’ beliefs and teaching practices related to inquiry in science taking into account the context of their reported practice. A tentative empirical framework containing four quadrants was developed to illustrate the dimensionality of teachers’ beliefs and teaching practices related to inquiry. Belief profiles were developed for each dimension in this framework based on the scale items in a revised Teachers’ Reported Beliefs measure.

Four types of teachers were identified and characterized based on their reported beliefs and teaching practices related to inquiry. Additionally, a stance was determined for each type representing the teachers’ generalized view of teaching and learning related to inquiry and a general theme was identified to represent each stance. The characterizations or beliefs profiles developed provided some evidence that teachers’ reported beliefs about teaching and learning related to inquiry influence their teaching practices. These characterizations also provide evidence that different types of teachers exist with different views and needs. Educational leaders and teacher-educators need to recognize that different types of teachers exist and take their differences into account when they are designing and delivering program support, most particularly professional development, in the goal of
providing effective professional development for all science teachers. The findings of this study provide evidence that one size will not fit all.

Anderson (2002) and Barrow (2006) argue that the dearth of open-ended inquiry in science will not be reversed until factors that serve as challenges to enactment are addressed. This chapter re-visited the challenges reported as significant to teachers’ enactment of open-ended inquiry considering them from the teachers’ perspective and linking them to teachers’ practice as well as recommended program support.

In chapter 8, I review the implications of this study; identify limitations of this study; and consider future directions related to this study.
CHAPTER 8
WHERE DO WE GO FROM HERE?

Implications: Inquiry and the Science Education Community

In spite of the slogan “Science for All” originally presented in 1916 (Uzzell, 1978, p. 13), Wellington (2001) states “the secondary school diet is still largely a slightly modified version of the traditional science curriculum originally designed for an academic minority” (p. 25). Other scholars agree that, although the goal for open-ended inquiry in science has been in place in science education for many decades, it continues to remain elusive, (Abd-El-Khalick et al., 2004; Barrow, 2006; Crawford, 2007; Melville & Bartley, 20010. It is my hope that this study has moved us closer to understanding teachers’ reported beliefs and practices related to inquiry.

In my study, I developed an empirical framework containing four quadrants to illustrate the dimensionality of teachers’ reported beliefs and reported teaching practices related to inquiry as practical work in science. Beliefs profiles were developed for each dimension in the framework. In addition, four types of science teachers were characterized by their reported beliefs and teaching practices related to inquiry. A stance was developed for each type based on these characterizations including: utilitarian science; content-based science; authentic contextual science; and citizenship science. A set of composite beliefs profiles was created to represent each quadrant in the framework and was incorporated into the framework.

The results of this study provide some evidence that teachers’ reported beliefs affect their teaching practices related to inquiry in science. This study also reported on challenges and identified program support needs. Challenges and types of program support reported as significant by survey
respondents and interviewees were compared and then merged. A triangulation design attempted to achieve both breadth and depth of perception in relation to the target population studied.

Kimble et al. (2006) maintained that “teachers are the key, and (that) they must be prepared and nurtured if the visions of reform are to be realized” (p. 309). My tentative framework and characterizations may inform administrators and educational leaders who must support each of these types of practicing teachers all of whom are charged with the role of implementing open-ended inquiry as practical science. In addition, this framework and the characterizations developed from it will assist in informing teacher-educators who (a) must prepare and support different types of practicing teachers who are implementing or planning to implement open-ended types of inquiry and (b) must prepare and nurture new generations of different types of science teachers committed to fulfilling the ministry’s second goal for science education (implementation of open-ended inquiry).

In regard to the goal for science education that incorporates science students engaged in open-ended inquiry, the results of this study seem to indicate that guided inquiry (preferred by teachers considered as holding a utilitarian science stance), where teachers retain some control over student investigations, could be regarded as a gateway to fully open-ended inquiry. In fully open inquiry teachers relinquish some control over the curriculum content by allowing students full independence in their investigations including the topic and problem being investigated. Furthermore, my study seems to indicate that structured inquiry (preferred by teachers considered as holding an authentic contextual science stance) is a gateway to guided inquiry. Lastly, this study suggests that a teachers’ stance plays a role in their beliefs and teaching practices related to inquiry. An implication here is that we need to pay attention to a teacher’s stance when considering professional development for practicing teachers and developing program for pre-service teachers in support of implementation of open-ended inquiry as practical science.
In 2000, the National Research Council stated: “Teachers know best what they need to learn and be able to do” (p. 80). Practicing teachers, in this study, identified factors that represented significant challenges to the enactment of open-ended inquiry in science and, then, discussed types of program support that would foster enactment. Several of the challenges identified and types of program support recommended are less commonly reported in the literature and may represent newer areas of study for researchers and important areas of consideration for educational leaders who are charged with the responsibility of fostering sustained teachers’ enactment of open-ended inquiry in science education.

Furthermore, my study suggests that, although there are common challenges and recommended types of program support across the four teacher profiles that I developed, there are also unique challenges and preferred types of program support that reflect teachers’ various stances. The implication here is that educational leaders and teacher educators need to pay attention to the kinds of professional development and other types of program support that are offered to teachers in the goal of fostering broad-based implementation of open-ended inquiry and recognize that one size does not and will not fit all.

This work also has implications for the development of policy pertaining to implementation of new curriculum documents. Teacher input needs to be included during the development of implementation plans and program support related to new curriculum documents. Additionally, this work has implications for curriculum developers. A more explicit curriculum with regard to implementation of different types of inquiry is called for. Moreover, attention needs to be paid to the way in which inquiry is defined and how it is portrayed in curriculum documents.

Lastly, the need for funding is well-documented in the literature and confirmed in my study. Funding is critical to the implementation of all types of inquiry as practical science. According to the
teachers in this study, the critical need for funding identified must be resolved. As a group, they report that, if this challenge is not resolved, funding shortages will only impede the goal of closing the inquiry gap in science education.

In summary, my study has implications for ministry policy. Curriculum documents need to be explicit. Additionally, this study has implications for board policy. Teacher input needs to be included during the development of implementation plans and program support related to curriculum documents. Lastly, there are implications for teacher education from the perspective of thinking about what needs to be provided in the way of teacher training to pre-service and in-service teachers and how it should be provided.

**Limitations of this Study**

A mixed methods design was selected for this study which explored four research questions pertaining to: teachers’ reported beliefs and teaching practices related to inquiry; identification of the challenges to enactment of open-ended inquiry; and recommendations for program support that would meaningfully foster open-ended inquiry as practical work in secondary school science. This study incorporated a three-stage, triangulation design (Creswell & Plano Clark, 2007) in data collection and analysis. Stage 1 included a self-reporting survey designed to collect quantitative data (measuring the strength of teachers’ agreement with each item on a 6-point Likert-type scale) and qualitative data (as teachers’ responses to open-ended questions). Stage 2 involved a short semi-structured interview designed to support participant selection for the Stage 3. In Stage 3, qualitative data was collected during an in-depth semi-structured interview.

This model allowed me to gather data that provided both breadth (Stage 1) and depth (Stage 3) of perception in relation to the phenomenon understudy (teachers’ enactment of inquiry as
practical science). However, because only one sample of science teachers was used to conduct item analysis and to compute reliability for items in the teachers’ belief measure (Stage 1), the estimates of reliability may represent overestimates for this population of secondary school science teachers employed by Pine Valley Board of Education. This, thereby, limits the potential for generalizability of the findings. Also, limiting the generalizability of these results is the fact that the level of consistency found was based on one relatively limited sample of secondary school science teachers ($n=83$). It should be noted, however, that this sample represented 80 percent of the total population of secondary school science teachers currently employed by the mid-sized public school board under study. All secondary schools in this Board of Education were involved in this study. As such, the results of this study are representative of this single population of practicing science teachers.

An additional weakness pertaining to the teachers’ reported belief measure is noted. Item analysis using the reliability procedures confirmed convergent and discriminant validity of the scales assessing each of the four constructs associated with the four components identified during principal components factor analysis. However, discriminant validity was weakened by one item of a total of seven items in the scale measuring the construct identified as an open-ended view of inquiry. This item was retained owing to its importance to the scale as a whole. It is, also, noted that the Teachers’ Reported Beliefs Measure should be revised to include an equal number of test items for each of the constructs being measured. The weakened discriminant validity limits the empirical basis for the framework developed to illustrate the dimensionality of teachers reported beliefs and teaching practices related to inquiry as practical work in science.

The characterizations of science teachers associated with the four stances (utilitarian science; content-based science; authentic contextual science; citizenship science) based on their reported beliefs and practices related to inquiry do not provide a framework for driving change in teaching
practice. As indicated earlier, these characterizations are based on a small number of practicing science teachers in a population of teachers employed by one board. However, having said this, the quantitative data does represent 80 percent of the science teachers in this Board. In addition, I do believe that some success was achieved in capturing the contextual ‘real life’ experiences and decision-making of the participants and, as such, is a reasonable representation of the population of science teachers under study. Therefore, the findings are limited in the extent to which they are transferable to other populations of science teachers working within other boards of education. It will be up to the readers of this study to determine the degree of transferability of the findings (Creswell, 2002).

Additionally, the Teachers’ Reported Beliefs Measure was not field-tested and has acknowledged weaknesses. However, the data obtained using this Beliefs Measure did succeed in providing an empirical basis for the development of my framework, in the early stages of this study. Problems with the Teachers’ Reported Beliefs measure will have to be corrected before it is used again but there is indication that this Beliefs’ Measure, once modified, offers potential future viability.

Lastly, it should also be noted that teachers may teach different types of inquiry to achieve their curricular goals. In doing so, teachers may associate with more than one stance. My framework represents teachers’ dominant emphasis with regard to their reported beliefs and teaching practices related to inquiry as practical science.

**Future Directions for Research**

I conclude my study with some thoughts about possibilities for future research. Having spent years as a teacher, department head and curriculum leader, facilitating and enacting open-ended
inquiry, I believe that my work here has provides some important findings and starting points, and some possibilities for further investigation. I see a number of future directions emerging from this work. Firstly, an investigation within classrooms of participants from each quadrant might assist in determining the extent to which teaching practice, related to inquiry, reflects reported beliefs about inquiry; and the extent to which reported practice is related to actual practice in teaching inquiry. These findings may add further confirmation to a substantial body of research reporting that teachers’ beliefs affect teaching practices.

Additionally, a study that examines the different ways in which teachers’ enact open-ended inquiry is recommended. I suggest that this study be connected to teachers’ views about the nature of science (NOS) and how teachers’ views impact on teaching practice related to inquiry. Such a study would shed light on teaching practices related to open-ended inquiry. Such a study would also shed light on the interaction between the nature of science and the implementation of open-ended inquiry.

I also recommend a longitudinal study focused on teacher-training programs to examine the relationship between pre-service teachers ‘doing’ open-ended inquiry in the role of students and their later enactment of open-ended types of inquiry as teachers. Such a longitudinal study could inform teacher-educators and contribute to modifying teacher-training programs so that they truly foster teachers’ enactment of open-ended inquiry as practical science in the classroom.

Two of the challenges identified in this study: (a) the view that open-ended types of inquiry are extra practical work; and (b) the time constraint on science education created by the semester program warrant investigation. I recommend that such studies be conducted both within the population of science teachers employed by Pine Valley School Board and beyond to determine the extent to which each of these challenges affects a teacher’s willingness to learn about implementation of open-ended inquiry and impedes his/her willingness to enact open-ended inquiry.
in the classroom even after knowledge and skills are in place to make this enactment possible. The findings of this study would inform educational leaders and the ministry.

Lastly, several factors have been identified that contribute to teachers’ general resistance to educational change. Teachers’ resistance emerged as a significant deterrent to enactment of open-ended inquiry. Research should be conducted to identify the basis and nature of this resistance as well as the impact of this resistance on teachers’ implementation of open-ended types of inquiry so as to determine how this challenge could be resolved by the school, the board, or the ministry.
REFERENCES


Appendix A
Excerpts from Ontario Curriculum Documents
Excerpts from the Ontario Curriculum

*Secondary Schools for the Twenty-first Century*

The goal of Ontario secondary schools is to support high-quality learning while giving individual students the opportunity to choose programs that suit their skills and interests. The updated Ontario curriculum, in combination with a broader range of learning options outside traditional classroom instruction, will enable students to better customize their high school education and improve their prospects for success in school and in life.

*The Place of Science in the Curriculum*

During the twentieth century, science played an increasingly important role in the lives of all Canadians. It underpins much of what we now take for granted, from life-saving pharmaceuticals to clean water, the places we live and work in, computers and other information technologies, and how we communicate with others. The impact of science on our lives will continue to grow as the twenty-first century unfolds. Consequently, scientific literacy for all has become a goal of science education throughout the world and has been given expression in Canada in the Common Framework of science Learning Outcomes, K to 1 to 12: Pan-Canadian Protocol for Collaboration on School Curriculum (Council of Ministers of Education, Canada, 1997). Scientific Literacy can be defined as possession of the scientific knowledge, skills and habits of mind required to thrive in the science-based world of the twenty-first century.

The overall intention is that all graduates of Ontario secondary schools will achieve excellence and a high degree of scientific literacy while maintaining a sense of wonder about the world around them. Accordingly, the curriculum reflects new developments on the international science scene and is intended to position science education in Ontario at the forefront of science education around the world.

*The Goals of the Science Program*

The three goals of the science program are as follows:

1. to relate science to technology, society, and the environment
2. to develop the skills, strategies, and habits of mind required for scientific inquiry
3. to understand the basic concepts of science

Every course in the secondary science program focuses on these three goals. The goals are reflected within each strand of every course in the three overall expectations, which in turn are developed in corresponding sets of related specific expectations. The same three goals also underlie assessment of student achievement in science.

*The Nature of Science*

Science is a way of knowing that seeks to describe and explain the natural and physical world. An important part of scientific literacy is an understanding of the nature of science, which includes an understanding of the following:

- What scientists, engineers, and technologists do as individuals and as a community
- How scientific knowledge is generated and validated, and what benefits, costs, and risks are involved in using this knowledge
- How science interacts with technology, society, and the environment
Occasionally, theories and concepts undergo change, but for the most part, the fundamental concepts of science—such as the cellular basis of life, the laws of energy, the particle theory of matter—have proved stable.

The Program in Science

Overview
The overall aim of the secondary science program is to ensure scientific literacy for every secondary school graduate. To better achieve this aim, all courses in the program are designed to focus on science not only as an intellectual pursuit but also as an activity-based enterprise within a social context.

The senior science courses build on the Grade 9 and 10 science program, incorporating the same goals of science and fundamental concepts on which the program was based. Both programs are founded on the premise that students learn science most effectively when they are active participants in their own learning. Such participation is achieved when science concepts and procedures are introduced through an investigative approach and are connected to students’ prior knowledge in meaningful ways.

A balanced science program must include varied opportunities for students to practice and enhance their scientific investigative skills. Like the Grade 9 and 10 science courses, the senior secondary curriculum focuses on refining specific skills that best enable students to develop their understanding of scientific concepts and acquire related knowledge.

Skills of Scientific Investigation (Inquiry and Research)
The goal of science education is more than just providing students with knowledge of the facts. Mastery of the subject can no longer be evaluated solely in terms of students’ ability to recall specialized terminology, memorize isolated facts, or repeat a theory. Rather, students must be given opportunities to learn through investigation. In doing so, they can practice and become proficient in various scientific investigation skills. These skills not only develop critical thinking and allow students to extend their understanding of science, they are also useful in students’ everyday lives and will help them in pursuing their post-secondary goals, whether in science or some other area of endeavour.

As students advance from grade to grade, they practice these skills more fully and independently and in increasingly demanding contexts. Initially, students become aware of and familiar with each new skill. With emerging understanding, students reflect on and practise aspects of these skills when conducting investigations. As their knowledge and confidence grow, students begin to implement the skill more fully. Through repeated use, they are able to increase and refine their understanding of and proficiency in each skill. Finally, once they become proficient, they can extend skills, incorporating them into other areas of study as well as everyday activities.

Four Broad Areas of Scientific Investigation
Students learn to apply scientific investigative skills in four broad areas: initiating and planning; performing and recording; analyzing and interpreting; and communicating.
Initiating and planning skills include: formulating questions or hypotheses or making predictions about ideas, issues, problems, or the relationships between observable variables, and planning investigations to answer those questions or test those hypotheses.

Performing and recording skills include conducting research by gathering, organizing, and recording information, and safely conducting inquiries to make observations and to collect, organize, and record data.

Analyzing and interpreting skills include: evaluating the adequacy of the data from inquiries or the information from research sources, and analyzing the data or information in order to draw and justify conclusions.

Communication skills include: using appropriate linguistic, numeric, symbolic, and graphic modes of representation, and a variety of forms, to communicate ideas, procedures, and results.

Skills in these four areas are not necessarily performed sequentially…Students should reflect on their questions, procedures, and findings, and should be prepared to modify them as they proceed through an investigation. In addition, each investigation is unique and will require a particular mix and sequence or skill.

Individual students may develop specific skills earlier or later than their peers, and some students may need to revisit particular skills at different points within the science curriculum. Skills in different areas may be practiced and refined in the context of tasks and activities that are not necessarily part of a single, complete investigation that involves all four areas.

**Strands in The Grade 9 and 10 Science Curriculum and in The Grade 11 and 12 Courses**

The first strand outlines required learning related to scientific investigation skills (SIS). The expectations in this strand describe the skills that are considered to be essential for all types of scientific investigation. These skills apply to all areas of course content and must be developed in conjunction with learning in all five content strands of the course. (Scientific investigations skills were also a focus of the elementary science and technology curriculum, but they were embedded in expectations within the content strands.)

The scientific investigation skills are organized under subheadings related to the four broad areas of investigation—initiating and planning; performing and recording; analyzing and interpreting; and communicating…Teachers should ensure that students develop the scientific investigation skills in appropriate ways as they work to achieve the curriculum expectations in content strands. Students’ mastery of these skills must be assessed and evaluated as part of students’ achievement of the overall expectations for the course.

**Instructional Approaches**

Students come to secondary school with a natural curiosity developed throughout the elementary grades. They also bring with them individual interests and abilities as well as diverse personal and cultural experiences, all of which have an impact on their prior knowledge about science, technology, the environment, and the world they live in. Effective instructional approaches and learning activities draw on students’ prior knowledge, capture their interest, and encourage meaningful practice both inside and outside the classroom. Students will be engaged when they are
able to see the connection between the scientific concepts they are learning and their application in
the world around them and in real-life situations.

Students in a science class typically demonstrate a diversity in the ways they learn best. It is
important, therefore, that students have opportunities to learn in a variety of ways—individually,
cooperatively, independently, with teacher direction, through hands-on experiences, and through
examples followed by practice.

In order to learn science and to apply their knowledge and skills effectively, students must develop a
solid understanding of scientific concepts. Research and successful classroom practice have shown
that an inquiry approach, with emphasis on learning through concrete, hands-on experiences, best
enables students to develop the conceptual foundation they need. When planning science programs,
teachers will provide activities and challenges that actively engage students in inquiries that honour
the ideas and skills students bring with them, while further deepening their conceptual
understandings and essential skills.

Critical Thinking in Science
Critical thinking is the process of thinking about ideas or situations in order to understand them
fully, identify their implications, and/or make a judgment about what is sensible or reasonable to
believe or do. Critical thinking includes skills such as questioning, predicting, hypothesizing,
analyzing, synthesizing, examining opinions, identifying values and issues, detecting bias, and
distinguishing between alternatives.

In developing the skills of scientific investigation (inquiry/research skills), students must ask
appropriate questions to frame their research, interpret information, and detect bias. Depending on
the topic, they may be required to consider the values and perspectives of a variety of groups and
individuals.

The purpose of inquiry and research is to encourage high levels of critical thinking so that processes
and resources are appropriate, conclusions are based on supporting evidence, and problems are
solved and decisions made that will extend learning for a lifetime.

Ontario School Library Association,
Information Studies: Kindergarten to grade 12
(1999), p. 10

The primary goal of science is to understand the natural and human-designed worlds. Science refers
to certain processes used by humans for obtaining knowledge about nature, and to the organized
body of knowledge about nature obtained by these processes. Science is a dynamic and creative
activity with a long and interesting history. May societies have contributed to the development of
scientific knowledge and understanding…Scientists continuously assess and judge the soundness of
scientific knowledge claims by testing laws and theories, modifying them in light of compelling new
evidence or a re-conceptualization of existing evidence.

SCCAO and STAO/APSO. Position Paper: The Nature
Change the focus of the curriculum and instruction from teaching topics to “using” topics to teach and assess deeper, conceptual understanding.  

Lynn Erickson, *Concept-Based Curriculum and Instruction* (2006), p.7

The goal of science education is more than just providing students with a knowledge of facts…Students must be given opportunities to learn through investigation. In doing so, they can practice and become proficient in various scientific investigation skills. These skills not only develop critical thinking and allow students to extend their understanding of science, they are also useful in students’ everyday lives and will help them in pursuing their post-secondary goals, whether in science or some other area of endeavour.  

The Ontario Curriculum Grades 11 and 12 (2008) p.20

As students advance from grade to grade, they practice these skills more fully and independently and in increasingly demanding contexts. Initially, students become aware of and familiar with each new skill. With emerging understanding, students reflect on and practice aspects of these skills when conducting investigations. As their knowledge and confidence grow, students begin to implement the skill more fully. Through repeated use, they are able to increase and refine their understanding of and proficiency in each skill. Finally, once they become proficient, they can extend skills, incorporating them into other areas of study as well as everyday activities.  

The Ontario Curriculum Grades 11 and 12 (2008) p.20

A much more effective way to learn is for students to be actively involved in thinking and discussing during both class and investigation activities, with the goal of having the students develop a deep understanding of scientific concepts.  

Appendix B
Ethical Approval
28 November 2008

Ann McIlmoyle
RR #1
Lakefield, ON
K0L 2H0

Dear Ms. McIlmoyle:

The Research Advisory Committee of the District School Board has reviewed your application to conduct research as outlined in your proposal entitled Enacting Open, Inquiry-based Science in Secondary School.

The Committee was impressed by the quality of the proposed research and recognises the importance of the information it will generate.

The Committee has approved your proposal to survey all secondary school science teachers and to follow up with those who volunteer for a face to face interview.

Please contact me for an initial discussion about facilitating communication with the secondary school science teachers, as the Teaching and Learning Department may be able to assist in this matter.

Please feel free to share this approval letter with school staff. I have contacted the secondary school Principals and their Supervisory Officers to inform them of the Research Advisory Committee approval for your study.

As always, the final decision on school participation remains with the Principal. The Committee asked me to express their appreciation for your application and to wish you well in your research. We look forward to receiving a copy of your final report when it is completed.

Sincerely,

Chair, Research Advisory Committee
University of Toronto  
Office of the Vice-President, Research  
Office of Research Ethics  

PROTOCOL REFERENCE #23422

December 18, 2008

Prof. Erminia Pedretti  
Dept. of Curriculum, Teaching and Learning  
Ontario Institute for Studies in Education  
of the University of Toronto  
252 Bloor Street West  
Toronto, ON M5S 1V6

Ms. Ann-Elizabeth McIlmoyle  
Dept. of Curriculum, Teaching and Learning  
Ontario Institute for Studies in Education  
of the University of Toronto  
252 Bloor Street West  
Toronto, ON M5S 1V6

Dear Prof. Pedretti and Ms. McIlmoyle:

Re: Your research protocol entitled “Enacting Open, Inquiry-based Science in Secondary School: Teacher Beliefs, Barriers and Meaningful Program Support”

ETHICS APPROVAL

| Original Approval Date: December 18, 2008 |
| Expiry Date: December 17, 2009 |
| Continuing Review Level: 1 |

We are writing to advise you that a member of the Social Sciences, Humanities & Education Research Ethics Board has granted approval to the above-named research study, for a period of one year, under the REB’s expedited review process. Please ensure that you submit an Annual Renewal Form or a Study Completion Report at least 30 days prior to the expiry date of your study.

The following consent documents (received November 24, 2008) have been approved for use in this study: Appendix C: Science Teacher Consent Form and Appendix D: Administrative Consent.

Any changes to the approved protocol or consent materials must be reviewed and approved through the amendment process prior to its implementation. Any adverse or unanticipated events should be reported to the Office of Research Ethics as soon as possible.

If your research has funding attached, please contact the relevant Research Funding Officer in Research Services to ensure that your funds are released.

Best wishes for the successful completion of your project.

Yours sincerely,

Raquel David  
Research Ethics Coordinator
Appendix C

Consent Forms
This study has been reviewed by OISE/UT, by University of Toronto’s Ethical Review Office, and by the Research Advisory Committee of DSB. If you would like more information, please contact me by phone at (705) 652-8692.

Please consider agreeing to the participation of your school’s science teachers in this important study. I hope that my findings will benefit each science teacher in your school and in the District School Board.

Thank you for taking the time to consider this study.

Sincerely,

Ann McIlmoyle

I, hereby, give my consent for science teachers in this school to participate in this study.

(Name of the Principal)  (Date)

(Secondary School)
February 1, 2009

Dear Head of Science:

I am a doctoral student at the University of Toronto conducting a study entitled “Enacting Open, Inquiry-Based Science in Secondary School: Teachers’ Beliefs, Barriers and Meaningful Program Support” under the supervision of Dr. Erminia Pedretti, Director of the Centre for Studies in Science, Mathematics & Technology Education at the University of Toronto.

At a time when inquiry-based science has been clearly identified as a major goal for all science education in Ontario, I am interested in determining the barriers that make the enactment of open, inquiry-based science at the secondary school level difficult for teachers and in identifying types of program support that would be meaningful to teachers. This study has been approved by the Ethical Review Office of the University of Toronto and by the Research Advisory Committee.

The purpose of this letter is to request that, as Head of Science, you contribute to this study by:

a.) distributing the two documents contained in this package (a Letter of Informed Consent and a Questionnaire) to each teacher in your department who teaches one or more sections of science during this school year (semester 1 and semester 2)

b.) collecting all signed Letters of Consent and completed Questionnaires

and

c.) returning these documents to me at the Education Centre of OISE in the enclosed, self-addressed envelop by Feb. 18.

It is my hope that the response rate achieved in this study will be high enough to contribute successfully to the development and funding of meaningful types of program support for science teachers both locally and provincially who are planning to enact or are in the process of enacting inquiry-based science at the secondary school level.

If you have any questions, please contact me by phone at 705-760-6513.

Thank you for your support,

Sincerely,

Ann McIlmoyle
Science Teacher Consent Form

Please complete the form on this page and place it in the envelope provided along with your completed questionnaire indicating that you are willing to participate in this study.

I have read the covering letter,
I understand that:

a.) In Part one of this study, I will be given a questionnaire to answer at a time convenient to me that will take about 15 minutes to complete.

b.) All data collected will be anonymous.

c.) Each questionnaire will have a numeric code and any information collected from me will be identified by this code only.

d.) Part two of this study will take the form of a personal, audio taped, one-on-one interview lasting approximately 30-60 minutes.

e.) Pseudonyms will be associated with all data collected and analyzed in Part two.

f.) Neither I, my colleagues, school(s), nor teachers with whom I work will be personally identified in any reporting of this study.

g.) A copy of this consent form will be available to me upon request.

h.) I can withdraw from this study at any time.

[ ] I agree to participate in Part one (a questionnaire) of this study.

[ ] I agree to participate in Part two (an interview) of this study.

Your Name: ________________________

Your Signature: ___________________

Date: _____________________________

Thank you for agreeing to participate in this study.

[ ] I wish to receive a summary of the findings of this study when the research is complete.

Please email the summary of findings to the following email address:
Appendix D

Revised Teachers’ Reported Beliefs Measure
Teaching Inquiry in Secondary School Science: 
Beliefs, Challenges and Program Support

Part A
Gender: F M
Grades taught: 9 10 11 12
Education: Bachelor’s Degree Master’s Degree Doctorate Degree Specialist’s Certification in Science Additional Certification _________________________________
Total Years of Teaching Experience: _____

Part B
Please circle the number indicating your level of agreement with each of the following statements:

1. I feel confident in my understanding of the science concepts and skills that I teach and my ability to communicate this knowledge to my students.
   Strongly Disagree Strongly Agree
   1 2 3 4 5 6

2. Teachers, not students, should determine the science content being covered in a lesson.
   1 2 3 4 5 6

3. I think of myself as being well-trained in the science content and skills that I teach.
   1 2 3 4 5 6

4. Being able to answer problems and complete assigned tasks quickly is confirmation of student understanding and ability.
   1 2 3 4 5 6

5. Students demonstrate good understanding of the scientific concepts and/or procedures being learned when they can give correct answers to the questions asked by the teacher.
   1 2 3 4 5 6

6. In science, most answers are either right or wrong.
   1 2 3 4 5 6

7. It is important for science teachers to relate what is being taught to real-life events and real-life problems.
   1 2 3 4 5 6
8. Good science instruction relates science to things that students are interested in outside of school.  
   1 2 3 4 5 6

9. Evaluation of student learning should include student improvement.  
   1 2 3 4 5 6

10. Giving marks on science assignments is a strategy that motivates students to work productively.  
    1 2 3 4 5 6

11. In science, students can be creative and make discoveries on their own.  
    1 2 3 4 5 6

12. Student collaboration during inquiry helps them to build understanding of concepts and principles being investigated.  
    1 2 3 4 5 6

13. Students preparing to become scientists need to master the related body of scientific knowledge available to them in textbooks.  
    1 2 3 4 5 6

14. In science education, it is important to engage students in scientific practices similar to those of real scientists.  
    1 2 3 4 5 6

15. Students in science should be encouraged to think carefully and logically.  
    1 2 3 4 5 6

16. As a teacher, I do not feel comfortable in the role of ‘guiding’ student learning from the ‘sidelines’. As a teacher, I prefer to ‘direct’ student learning.  
    1 2 3 4 5 6

17. I, often, allow my students to do experiments by following a specified procedure in order to verify previously learned scientific principles.  
    1 2 3 4 5 6

18. When I teach science, I include some laboratory exercises in which I provide the students with a problem to be solved and the procedure to be followed in order to support their acquisition of new, pre-determined learning.  
    1 2 3 4 5 6
19. To support effective learning in science, I believe that it is important for students to be given specific procedures to follow when they are engaged in scientific investigations.  

20. In order to achieve effective learning in science, students must learn to follow all instructions given.  

21. In my science classes, practical science includes the opportunity for students to acquire new learning by designing and conducting an investigation to answer a scientific problem provided to them.  

22. In my science classes, I provide the opportunity for students to acquire new learning by: posing a question on a topic of interest to them; designing an investigation to answer their question; collecting, and analyzing data; and communicating the results of their investigation.  

Please answer the following additional questions: 

23. Did you, as a science student, have the opportunity to pose and investigate problems on topics of interest to you?  

Yes  No

If yes, at what level(s) of science education did this opportunity occur?  
i.) Elementary school  
   Yes  No  
ii.) Secondary school science  
    grade(s) 9 10 11 12 13  
iii.) Post-secondary science  
iv.) Graduate school science

24. As a secondary school teacher, which factors serve as challenges to your implementation of inquiry as practical science?
25. What type(s) of inquiry do you currently implement in your science classroom?

26. What type of program support do you believe would foster your implementation of inquiry in your science classes?

Additional Comments can be placed on the back of any question page.

Thank you for answering this questionnaire.
[ ] I earlier confirmed my willingness to participate in phase two of this study.
Appendix E
Interview Protocols
E 1

Stage 2: Interview Protocol

Teacher ___________________
School ___________________
Gender M F

1. How many years have you been teaching?

2. Which science courses have you taught in the last two years?

3. What types of inquiry do you teach in your science classes?
   Briefly describe each type.

4. Which type of inquiry do you prefer to teach?
E 2
Stage 3: Interview Protocol

Thank you for agreeing to participate in Stage 2 of this study.

Participant Information:
ID_______ Gender _______ Years of experience ______
Position(s) of Responsibility: _____________________________________________
Qualifications: (including degree and all additional qualifications)
_______________________________________________________________________
Teaching experience (science courses): ______________________________________
____________________________________

1. Did you, as a student, have the opportunity to pose and investigate problems on topics of interest to you during your secondary school, post-secondary school and/or graduate school science education? If yes, describe your experiences.

2. a) Do you believe that science education, at the secondary school level, should include providing students with the opportunity to pose and investigate a scientific problem in a topic area of interest to them? Why or why not?
   b) Should this opportunity be available to all students in secondary school science? If no, who should be exempted?

3. a) Do you believe that secondary school science should provide students with the opportunity to independently investigate a problem provided to them by their teacher? Why or why not?
   b) Should this opportunity be available to all students in secondary school science? If no, who should be exempted?

4. a) In which grades have you taught inquiry as practical science?
   Describe each of your different approach(es) to teaching inquiry in science?
   b) Which type(s) of inquiry do you prefer to teach?

5. a) When your students do independent scientific investigations, do you include communication of results as an in-class, oral presentation?
   b) Is this oral presentation in place of or in addition to a written report?

5. How would you describe your role and responsibility as a science teacher at the secondary school level?

6. What are your curricular priorities as a science teacher?
7. a) Which barriers would you identify as impeding the enactment of open-ended types of inquiry in science?
   b) From your perspective, which of these barriers to enactment are the most significant and which are the least significant to enactment of open-ended inquiry?
   c) Which of these barriers have you been able to overcome and how have you done so?

8. a) What types of program support do you think would serve to overcome these barriers and foster the implementation of open-ended types of inquiry?
   b) How would you rank these types of program support?
Appendix F
Data Tables
Table F1
*Participant Demographic Information: Stage 1*

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<th></th>
<th>Female Teachers</th>
<th>Male Teachers</th>
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<td>Specialist in Chemistry</td>
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<td>Specialist in Special Education</td>
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<td><strong>Teaching Experience (years)</strong></td>
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Table F2
Interview Participants and Demographic Information

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<tr>
<th>Participant</th>
<th>Gender / stance</th>
<th>Experience (years)</th>
<th>Teaching degree</th>
<th>Specialist certification</th>
<th>Head</th>
<th>Primary area(s) of teaching</th>
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<tr>
<td>Tom</td>
<td>M (U)</td>
<td>27</td>
<td>BSc MSc</td>
<td>No</td>
<td>No</td>
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<td>Sam</td>
<td>M (U)</td>
<td>5</td>
<td>BSc</td>
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<td>No</td>
<td>Physics / Math</td>
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<td>George</td>
<td>M (U)</td>
<td>15</td>
<td>BSc</td>
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<td>No</td>
<td>Physics / Chemistry</td>
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<tr>
<td>Paul</td>
<td>M (U)</td>
<td>12</td>
<td>BSc</td>
<td>Yes</td>
<td>Yes</td>
<td>Biology/Chemistry</td>
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<tr>
<td>Sarah</td>
<td>F (CBS)</td>
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<td>Jill</td>
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<td>Linda</td>
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<td>Mark</td>
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<td>BSc MEd</td>
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<tr>
<td>Jeff</td>
<td>M (AS)</td>
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<td>Laura</td>
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<td>Tina</td>
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<td>Tanis</td>
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<td>Andrew</td>
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Note. U = Utilitarian Science; AS = Authentic Contextual Science; CBS = Content-Based Science; CS = Citizenship Science.
### Table F3

**Item-Total Statistics for the Teachers’ Reported Beliefs Measure**

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<th>Item #</th>
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<td>Teacher Belief Items</td>
<td>Means (SD)</td>
<td>Corrected Item-TOTAL Correlation</td>
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<tr>
<td><strong>Teacher-Directed View of Learning (TDL)</strong></td>
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</tr>
<tr>
<td>Teacher confidence in training</td>
<td>5.24 (.79)</td>
<td>.361</td>
</tr>
<tr>
<td>Teacher confidence in mastery of scientific knowledge</td>
<td>4.08 (1.01)</td>
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<td>Mastery of scientific knowledge as preparation for future education in science</td>
<td>5.00 (.88)</td>
<td>.389</td>
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<tr>
<td>Teacher control of student learning (content and skills)</td>
<td>3.97 (1.09)</td>
<td>.315</td>
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<td>Answering questions quickly as evidence of academic capability</td>
<td>3.22(1.17)</td>
<td>.623</td>
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<tr>
<td>Correct answers to questions as evidence of learning in science</td>
<td>4.32 (1.09)</td>
<td>.364</td>
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<tr>
<td>Marks as motivators</td>
<td>4.04 (1.25)</td>
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<tr>
<td><strong>Student-Directed View of Learning (SDL)</strong></td>
<td></td>
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</tr>
<tr>
<td>Science instruction should relate to students’ interests</td>
<td>5.27 (.98)</td>
<td>.120</td>
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<tr>
<td>Science education should relate to real-life events and issues</td>
<td>5.61 (.80)</td>
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<td>Students can be creative</td>
<td>5.02 (.93)</td>
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<tr>
<td>Student collaboration is important to learning</td>
<td>5.23 (.79)</td>
<td>.167</td>
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<tr>
<td>Evaluation includes student improvement</td>
<td>5.35 (.79)</td>
<td>.187</td>
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Table F4 (continued)

Means and Standard Deviations for Teachers’ Reported Belief Items (revised measure)

<table>
<thead>
<tr>
<th>Teacher Belief Items</th>
<th>Means (SD)</th>
<th>Corrected Item-Total Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Open-Ended View of Inquiry (OEI)</strong></td>
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<td>(N=83)</td>
</tr>
<tr>
<td>Teacher as a facilitator (reversed scale)</td>
<td>4.15 (1.32)</td>
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<tr>
<td>Scientific practices similar to those of real scientists</td>
<td>4.83 (0.87)</td>
<td>.189</td>
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<tr>
<td>Student independence in investigations</td>
<td>3.36 (1.08)</td>
<td>.230</td>
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<tr>
<td>Students’ independence in investigating problems posed by others (guided inquiry)</td>
<td>4.55 (1.23)</td>
<td>-.081</td>
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<tr>
<td>Students’ independence in investigating a problem which they have posed in a topic area of interest to them (fully open inquiry)</td>
<td>3.90 (1.61)</td>
<td>.186</td>
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<tr>
<td>Students following ‘recipe’ labs do not achieve the most effective learning</td>
<td>3.04 (1.27)</td>
<td>.317</td>
</tr>
<tr>
<td>Scientific knowledge as tentative not fixed</td>
<td>4.04 (1.25)</td>
<td>.110</td>
</tr>
<tr>
<td><strong>Closed-Ended View of Inquiry (CEI)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emphasis on precise and logical thought</td>
<td>5.07 (1.01)</td>
<td>.366</td>
</tr>
<tr>
<td>Practical science which includes students doing experiments by following a specified procedure in order to verify previously learned scientific principles</td>
<td>4.77 (.94)</td>
<td>.404</td>
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<tr>
<td>Practical science which includes students doing experiments in which a problem is provided along with the procedure to follow in order to support the acquisition of new, pre-determined learning</td>
<td>4.70 (.97)</td>
<td>.379</td>
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Table F5
*Correlation of Each Belief Item with Its Own Scale after Removing the Belief Item (in Bold Type) and with each of the other Belief Scales*

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<thead>
<tr>
<th>Belief Items</th>
<th>Factors</th>
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<tr>
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<td>TDL</td>
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<tr>
<td><em>(n=83)</em></td>
<td></td>
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<tr>
<td><strong>Teacher-Directed View of Learning (TDL)</strong></td>
<td></td>
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<tr>
<td>Teacher confidence in training</td>
<td>.51</td>
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<td>Teacher confidence in mastery of scientific knowledge</td>
<td>.59</td>
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<tr>
<td>Mastery of scientific knowledge as preparation for future education in science.</td>
<td>.53</td>
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<tr>
<td>Teacher control of student learning (content and skills)</td>
<td>.54</td>
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<tr>
<td>Answering questions quickly as evidence of academic capability</td>
<td>.62</td>
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<tr>
<td>Correct answers to questions as evidence of learning in science</td>
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<tr>
<td>Marks as motivators</td>
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Table F5 (continued)
*Correlation of Each Belief Item with Its Own Scale after Removing the Belief Item (in Bold Type) and with each of the other Belief Scales*

<table>
<thead>
<tr>
<th>Beliefs Items</th>
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<tr>
<td>Student independence in investigations</td>
<td>.14</td>
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<tr>
<td>Student independence in investigating a problem posed by others (guided inquiry)</td>
<td>.28</td>
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<tr>
<td>Students acquiring new learning by posing and investigating a problem in an area of interest to them (fully open inquiry)</td>
<td>-.13</td>
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<tr>
<td>Students following ‘recipe’ labs do not achieve the most effective learning</td>
<td>.02</td>
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<tr>
<td>Scientific knowledge is tentative not fixed</td>
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</table>
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<td>Science instruction should relate to real-life events and issues</td>
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<td>Students can be creative</td>
<td>-.04</td>
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<tr>
<td>Student collaboration is important to learning</td>
<td>-.12</td>
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<td>Evaluation includes student improvement</td>
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<tr>
<td><strong>Closed-Ended View of Inquiry (CEI)</strong></td>
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<tr>
<td>Emphasis on logical and precise thought</td>
<td>.30</td>
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<tr>
<td>Student investigations as ‘recipe’ labs for verification of previously learned scientific principles (confirmation inquiry)</td>
<td>.22</td>
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<td>Student investigations as ‘learning by discovery’ (structured inquiry)</td>
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<tr>
<td>Participant</td>
<td>Reflections on ‘doing’ inquiry-based science as a student</td>
</tr>
<tr>
<td>-------------</td>
<td>----------------------------------------------------------</td>
</tr>
<tr>
<td>Tom</td>
<td>“It was great …the freedom. I guess the power of knowing what you’re doing is yours alone and you didn’t really have any restrictions in terms of what you did or how you did it…I have no memory of anything else that I studied in high school science.”</td>
</tr>
<tr>
<td>George</td>
<td>“Whenever it (nuclear winter) comes up…I read it… I have this connection.”</td>
</tr>
<tr>
<td>Andrew</td>
<td>“I was lucky. Basically every year (in high school) we had to do a science fair project…It has framed the way I teach.”</td>
</tr>
<tr>
<td>Linda</td>
<td>“Working through the process was fun, it was exciting, it was liberating and it was empowering to be able to decide on our own… I remember clearly working those projects… It was interesting, it was relevant, it was engaging. I don’t remember much else about what I studied in those years. I remember sitting in my science classrooms a lot and taking a lot of notes and reading the book a lot.”</td>
</tr>
<tr>
<td>Paul</td>
<td>“I enjoyed the experience. It was great. I had no idea what to expect.”</td>
</tr>
<tr>
<td>Brian</td>
<td>“It developed a curiosity in me and I think results were probably much better than somebody telling me about the topic. We got to choose what we wanted to do. …You develop a lot of skills, and a lot of knowledge that you are interested in.”</td>
</tr>
<tr>
<td>Kristen</td>
<td>“I was very excited … I thought it was fantastic.” “Here I was learning something that I wasn’t told to learn but that I had sort of a vested personal interest in and,…then, as I got in deeper and deeper, I was going, wow, this is kind of amazing.”</td>
</tr>
<tr>
<td>Susan</td>
<td>“I do remember being able to select topics of interest to me. It was a great experience, a valued experience for me.”</td>
</tr>
<tr>
<td>Nicole</td>
<td>“I was intensely motivated (in science) by the process of doing a classroom project. It consumed my whole being.”</td>
</tr>
<tr>
<td>Jill</td>
<td>“Positing hypotheses, collecting data and trying to think intelligently. I enjoyed it...It was great.”</td>
</tr>
<tr>
<td>Jeff</td>
<td>“I was so interested in this topic. I learned so much about it… Now, when the topic comes up, I always remember. I am still connected to this topic.”</td>
</tr>
<tr>
<td>Participant</td>
<td>Reflections on ‘doing’ inquiry-based science</td>
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<tr>
<td>-------------</td>
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<tr>
<td>Sam</td>
<td>“The topic that I wanted to do was the manufacture of gunpowder and because of the safety issue involved, I was not allowed to proceed. I did it on my own time anyway. The experience was great. I learned a lot. I don’t recall the topic chosen for me or what I did.”</td>
</tr>
<tr>
<td>Laura</td>
<td>“I liked going to the lab. I liked going to the library and looking up papers related to the topic and finding that I could actually read them and understand them. I still love that topic.”</td>
</tr>
</tbody>
</table>