Science Teachers' Conceptions of Scientific Concepts

by

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ABSTRACT

The purpose of this study was to examine practicing teachers' understandings of the use of misconceptions in building new scientific knowledge as well as their personal understandings of common scientific misconceptions. 91 participants from a non-random sample of teachers who teach science at the grades 5 through 8 levels completed a paper-based questionnaire of which 6 were subsequently interviewed. The data collected included demographic data (gender, age, teaching experience, and educational background), a self-assessment of personal content knowledge, a survey of classroom practices utilized, and a series of science ideas that were evaluated as either true or false by the participants. Various relationships between these data were identified. It was found that age and teaching experience had no effect on participants' abilities to identify misconceptions. In addition, participants with more scientific backgrounds were better able to identify misconceptions. Conclusions include the need for explicit instruction about the role of misconceptions in preservice teacher education and through improved professional development opportunities for science teachers.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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Here I am faced with the perennial question when writing these types of things – do you put the person who you want to thank most at the beginning or at the end? To resolve this, I will mention her in both places:

Katie, you have been the person who has made this all possible and for that I am eternally grateful. More about your contribution later!

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DEDICATION

For my family

CHAPTER 1

INTRODUCTION AND RATIONALE

Introduction to the Problem

In 1997, the Council of Ministers of Education, Canada (CMEC), published the Common Framework of Science Learning Outcomes in an effort to reform science education in Canada. They felt that "all Canadian students … will have an opportunity to develop scientific literacy. Scientific literacy is 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). This strong statement is meant to guide educators away from the traditional or expository teaching of science towards developing and implementing classroom practices that cause students to think and act like scientists.

Documents like the Common Framework are simply the latest efforts towards reform of science education. For example, science education in the 1950s was based on memorization and accumulation of facts taught by lecture, teacher demonstrations and by reading textbooks (Bright, 2001). A curricular reform movement began in the late 1950s following the launching of Sputnik by the Soviet Union whereby the processes of science were focused on as much as the content knowledge, however this reform lost momentum in the 1970s. (Keeves & Aikenhead, 1995; Lederman, 1992)

In 1989, the American Association for the Advancement of Science (AAAS) published the document "Science for All Americans" as another effort to reform the teaching of science in schools. The document states that cognitive scientists have established "that even with what is taken to be good instruction, many students, including academically talented ones, understand less than we think they do" (AAAS, 1989, p. 198). It also suggests that students need to connect what they are learning in science class with their existing ideas and that teachers should not expect students to grasp abstract ideas until they have had experience with concrete examples (AAAS, 1989).

These critiques of science education led to the development of the curriculum reforms documents such as National Science Education Standards (NRC, 1996) in the United States and the Common Framework of Science Learning Outcomes (CMEC, 1997) in Canada. These reforms all intend to "(1) create schools that have mediation of learning as their primary goal and (2) produce teachers who, as professionals, can lead, guide, and mediate the learning processes so that (3) learning becomes a way of life and schools become communities of learning" (Tobin, Tippins & Gallard, 1994). Departing from the format of traditional curriculum documents, these publications emphasized *how* science should be taught in classrooms as opposed to focusing simply on *what* should be taught.

This change in focus is rooted in the latest epistemological research that explored how knowledge is acquired and refined. This epistemology, known as constructivism, is seen to be the most dominant influence in science education today (Matthews, 2002). Constructivism is based on the concept that learners build new knowledge using their prior knowledge as a foundation. This epistemology builds on the work of Piaget (1954), Vygotsky (1978), and Ausubel (2000) amongst others who all suggest that childrens' prior experiences and understandings can be transformed into new knowledge if their minds are engaged (Sterling, 1999). Constructivist educators are those who provide challenges to students' prior knowledge and opportunities to experiment in order to create a new understanding of a concept. The relatively recent emergence of a number of science education texts that focus on constructivist teaching strategies (Carin, et al., 2005; Koch, 2005; Martin, et al., 2005) seems to suggest that these are the predominant strategies being taught to preservice science teachers for use in classrooms.

There are a number of strategies teachers can use in their science classrooms that would be considered constructivist. Many of these strategies are combined and are described as 'inquiry learning'. Inquiry learning is a classroom approach that integrates hands-on activities (such as using manipulatives, performing experiments, or making models), questioning strategies and assessment techniques, all designed to challenge prior assumptions and beliefs in an effort to create new understandings (Carin, et al., 2005).

Prior knowledge is acquired through lived experiences as much, or more, than from a formalized setting such as a classroom (Colburn, 2000). Television shows, works of fiction and urban myths are all methods by which children acquire some knowledge of scientific concepts. Of course, some of this information is not commonly accepted as being true by scientists and can provide teachers with a barrier that needs to be overcome for students to gain the correct conception. A particular example of this is found in the popular television cartoon, *The Simpsons*, where the entire half-hour episode focuses on the conception that water swirls in a particular direction as it flows down a drain depending which hemisphere it is in (Oakley, Weinstein & Archer, 1995). This premise, based on a natural phenomenon known as the Coriolis force – the effect of the earth's rotation on large pockets of air to cause hurricanes and cloud vortexes – does not apply to small bodies of water, such as that found in a bathroom sink (Fraser, 1995). In fact, the shape of the bathroom fixture is what determines the direction that water flows down the drain (Fraser, 1995).

A specific constructivist approach that allows students' misconceptions to be challenged and incorporates all features of inquiry learning is known as a learning cycle. The original approach, developed by Robert Karplus and Chester Lawson as they worked on the Science Curriculum Improvement Study during the 1950s, involved teaching a concept using three 'phases' – inquiry, instruction, and application (Lawson, Abraham & Renner, 1989). Lawson, Abraham, and Renner (1989) consolidated the research into a National Association for Research in Science Teaching (NARST) monograph where they refined and renamed the three phases as exploration, term introduction and concept application. They also detail three different types of learning cycles, each with a slightly different level of sophistication that allows the learning cycle to be used at any grade level.

This research on the learning cycle produced a great deal of literature on its efficacy and many of these studies resulted in refinements in the learning cycle (Blank, 2000; Lavoie, 1999; Libby, 1995; Marek, Eubanks, & Gallaher, 1990). All these studies concluded, however, that inquiry learning and the learning cycle seemed to be a superior method of teaching science in such a way as to increase understanding and apply the concepts to new situations.

To summarize, constructivism is regarded as the predominant theory that explains how knowledge is acquired. Inquiry is an attempt to put the theory of constructivism into practice. Finally, the learning cycle is presented as a 'best practice' of implementing inquiry in a classroom setting.

Central to all the research on constructivism, inquiry and learning cycles is the concept that the use of prior knowledge is fundamental to creating new knowledge. Many students hold misconceptions – prior knowledge that does not match the currently accepted understandings by scientists – about a number of basic scientific concepts. As a result, a great deal of study has been done to identify misconceptions that the students often have acquired through lived experiences or through instruction. (Arnaudin & Mintzes, 1985; Brumby, 1984; Simpson & Marek, 1988; Wandersee, 1986; Wandersee, Mintzes, & Novak, 1994). Constructivist teachers are required to determine students' misconceptions and provide activities that will challenge the students' prior knowledge and force them to adapt or assimilate their knowledge (Carin, et al., 2005).

Regardless of the research and reform efforts, constructivist practices are not being used widely in North American science classrooms. A recent study of American middle school (grades five through eight) classrooms showed that, while constructivist practices were being used in some classrooms, the predominant methods for teaching science continue to be whole class discussion, lecturing, providing notes, and assigning textbook and worksheet activities (Fulp, 2002). The report found that less than 25% of class time, on average, was spent doing hands-on activities, using manipulatives or doing laboratory activities. Although almost three-quarters of the teachers surveyed reported doing these types of activities at least once per week, "students were much more likely to be asked to follow specific instructions in completing an activity or investigation than to design their own investigations" (p. 17). It is important to note that inquiry is not successful when students are simply *doing* an activity or process, but do not understand why the activity is being done and what might result from it (Abd-el-Khalick, et al., 2004).

There are a number of possibilities as to why teachers are not incorporating inquiry learning into their science classes. Songer, Lee, and McDonald (2002) suggest that pressure to perform well on standardized tests, lack of resources or lack of infrastructure are reasons often cited by teachers. Other systemic reasons could include teachers not having adequate preparation time to plan and assess inquiry-based lessons or their schools' timetables may not allow students enough time to become engaged in an exploration.

Beck, Czerniak, and Lumpe (2000) mention that many teachers have little knowledge of or belief in the theory of constructivism. They also make the connection between teachers' beliefs and classroom practices and suggest that low knowledge or commitment to constructivism will result in teachers not using inquiry learning in their classrooms.

Teachers' conceptions of the nature of science may also play a part. The nature of science refers to the knowledge of and attitudes towards science as a discipline. Many people see science simply as a collection of facts and explanations rather than a way of finding out about the natural world (McComas, 1998). Black (2003) and Bright (2001) have researched the relationship of how teachers who have a better understanding of the nature of science and the processes scientists use result in better classroom practices.

A further explanation could be simply a lack of science content knowledge amongst teachers. Fulp (2002) specifies middle school teachers' (grades five through eight) apparent lack of content knowledge as measured by teachers self-reporting their educational backgrounds. Kikas (2004) mentions "the content knowledge of teachers fails to meet the standards required by contemporary elementary-school curricula and that they have various misconceptions" (p.435).

Identifying students' misconceptions is central to inquiry learning. Studies have been performed to identify and probe misconceptions held by preservice or practicing teachers (Kikas, 2004; Haidar, 1997). Studies such as these are important as "[t]eachers' own fragmentary knowledge and misconceptions act as obstacles, especially in using student-centered, active teaching methods" (Kikas, 2004, p. 444). A teacher's misconceptions of scientific concepts may indicate two problems: a lack of content knowledge on the part of the teacher and the unlikelihood of the teacher to be able to identify students' misconceptions.

Rationale

Inquiry-based teaching methods, based on the constructivist epistemology have been shown to be the best way to help students learn science. However, many students are not learning science in these settings. There are a number of potential barriers that prevent teachers from employing inquiry methods in their classrooms, including a lack of access to resources, time commitments, concerns over high-stakes testing of students, or a lack of awareness on the teacher's part about how science is learned. In addition, one of the barriers recently identified in the literature is the problem of teachers harbouring a number of misconceptions about scientific concepts (Kikas, 2004). A high level of science misconceptions may indicate that the teacher has low content knowledge (Kikas, 2004). A consequence of this is that the teacher may have difficulty identifying and targeting similar misconceptions in students, which is one of the main strategies used in inquiry-based learning. The causes of these misconceptions may be related to a number of factors, including the current practice of university teaching programs producing generalist teachers who are not required to have a stronger background of science content knowledge (Kikas, 2004).

Very little research exists concerning the specific misconceptions held by teachers of science, the root causes of those misconceptions or connections between the misconceptions held by teachers and other factors such as their educational background, years of experience, or their preferred classroom strategies. The purpose of this study is to examine conceptions of scientific concepts held by science educators and their relationships between the participants' demographic data, educational background, opinions regarding personal science knowledge, and classroom practices. Any relationships found between the demographic data and either the number or type of misconceptions will be explored in greater depth through the use of interviews. This research will hopefully provide insight about how teacher preparation may be improved for prospective teachers and how to develop improved professional development opportunities for those already in the classroom.

Chapter 2 contains a review of literature that pertains to constructivism, inquiry, misconceptions, and barriers to the implementation of inquiry in classrooms. The methods of this study are detailed in chapter 3. Chapter 4 contains an analysis of the quantitative data gathered through the questionnaires and the qualitative data gathered using interviews. Finally, chapter 5 provides discussion of the results, conclusions, and recommendations for improved teacher education, professional development, and further research.

CHAPTER 2

REVIEW OF LITERATURE

Introduction

This literature review includes an examination of the ontology and epistemology of science, a review of constructivism as an epistemology and its dominant themes, and present inquiry learning as the predominant method of using constructivist practices in the classroom. The learning cycle is presented as an example of inquiry learning that embodies the fundamentals of the interactive-constructivist model. Finally, research concerning possible barriers to the implementation of inquiry in science classrooms is summarized.

Ontology and Epistemology of Science

A spectrum of views

As discussion of science education reforms became more prevalent, it became necessary to more deeply understand the nature of how science is performed and how scientific information is known. This section explores these two topics as being the underpinnings of science education. Good, Shymansky, and Yore (1999) and Bright (2001) list three views of science – traditional, contemporary and postmodern.

The traditionalist (or absolutist) view is rooted in the scientific revolution of the seventeenth century, which was a catalyst for the exploration of how humankind is connected to the natural universe (Brown, 2003). This view of science posits that there are universal truths in the natural world that can be discovered through scientific processes. Bacon and Locke were early philosophers who describe science as the quest for truths and the confirmation of these truths through sensory observations as empiricism and positivism (Good, Shymansky & Yore, 1999). This view stresses inductive reasoning, where observations are synthesized into generalizations where "people focus on exemplars to eliminate noncritical features and to emphasize necessary and essential characteristics by comparing and contrasting examples and nonexamples" (p. 102).

Following the empiricist and positivist philosophies came rationalism of which René Descartes and Immanuel Kant were the principal proponents. Rationalism refers to using humankind's intellect to again "find and confirm truths" (p. 103) using deductive processes. Deduction is attempting to define truth using generalized statements than can be used to predict future occurrences (Yore, Hand & Florence, 2004).

Inherent to both of these approaches is that using them "a theory could never be proven to be correct in all respects, could never be shown to be logically complete" (Brown, 2003) especially as they require observations to hold true in all situations – including those in the past and the future (McComas, 1998). This leads to the contemporary (or evaluative) view where knowledge is "a set of temporary descriptions that best fits the existing evidence and current understanding of the real world within the limitations of peoples' sensory and intellectual abilities" (Bright, 2001). The modern view of science asserts "knowledge claims are not absolute, only supported or falsified" (Yore, et al., 2004, p. 342). This view of science is more dynamic as scientists continually refine arguments, claims and theories to match the data and observations currently available.

More recently, a postmodern (or relativistic) view of science has emerged. Scientists and philosophers such as Harding (Hand, Prain & Yore, 2001) and Polanyi (Brown, 2003) argue that science cannot be separated from the people who do it and the context in which it is done. Yore, et al. (2004) say scientists "use multiple ways to construct these descriptions and explanations [of the world] in the context of their own personal experiences, beliefs, cultural values, and situations (times/places)" (p. 342). Polanyi goes further to state that scientists use unconscious tacit knowledge and intuition that are often inexplicable (Brown, 2003) – a sharp contrast to the exactitude promoted by the seventeenth century philosophers.

These seemingly diverse definitions of the nature of science and the nature of scientific knowledge do share a number of common characteristics. Good, et al. (1999) state that throughout all definitions of science "the importance of observations, quality of evidence and argument, logic, imagination, and critical thinking [remain] central…" (p. 103). This statement implies that underneath any view of science lies a core of procedures, scientific skills and character traits that are necessary for a scientist and his or her theories to be accepted by the scientific community. None of these definitions have been completely adopted or wholly discarded by the scientific community – parts of all of them exist concurrently.

View of science held by reform documents

Science education reform documents such as "Science for all Americans" (AAAS, 1989), "National Science Education Standards" (NRC, 1996) and the "Common Framework of Science Learning Outcomes" (CMEC, 1997) all use the contemporary, evaluative view to guide their recommendations. These documents all assert that students should develop awareness of the "big ideas" in science, possess habits of mind that encourage critical thinking, and develop communication skills in order to share and discuss their knowledge (Bright, 2001). All of these skills are necessary when knowledge is seen as temporary – something that can change if compelling new evidence and arguments are put forth.

Conceptions about the nature of science held by teachers

As might be expected with a diverse set of views regarding the nature of science, students and teachers have a variety of conceptions and assumptions about what they believe science to be and what it is able to do for society. McComas (1999) list some of these "myths" and explains how they often interfere with quality science teaching and learning. The myths include that a universally accepted scientific method exists, hypotheses mature into theories and then into laws, science is able to solve all problems and science is more procedural than creative (McComas, 1999).

More recently Bright (2001) and Black (2003) have explored explicit instruction about the nature of science to preservice teachers in an effort to improve science teaching practices in school classrooms. They both found that improving teachers' knowledge of the nature of science translated improved attitudes towards teaching science and greater willingness to implement inquiry activities.

Constructivism and Inquiry

Introduction

Constructivism is seen to be a dominant, if not the most dominant, influence in science education today (Matthews, 2002). Constructivism is an epistemology that is based on the concept that learners build new knowledge using their prior knowledge and experiences as a foundation for constructing new knowledge claims (Cates, 2001). This epistemology is rooted in the work of Piaget (1954), Vygotsky (1978), and Ausubel (2000) amongst others who all suggest that children's prior experiences and understandings can be transformed into new knowledge if their minds are engaged and their previous constructs challenged (Sterling, 1999).

It is viewed by many, then, that a requirement for this type of learning to take place, an "authentic learning situation with authentic learning tasks" (Cates, 2001, p. 3) is required. Authentic learning situations and tasks take place in a social context that encourages interaction between students, shared thought and negotiation and consensus building (Cates, 2001; Fraser & Wubbels, 1995).

Bright (2001) summarizes the four potential responses students may make when their prior knowledge and understandings are challenged. They may reinforce, solidify or expand the prior conceptions if the new knowledge 'agrees' with the old. If the new knowledge is in conflict with the old, the students may replace their previous concepts with new ones, they may refuse to accept the new knowledge and remain in a state of what Piaget called "disequilibration" or they may simply wait for the teacher to provide the 'correct' answer and simply memorize it.

'Themes' of constructivism

As with all epistemologies, there is no general theory of constructivism that suits all theorists and scholars. Henriques (1997) and Yore (2001) identify four main themes of constructivism that describe a spectrum of interpretations that focus on different epistemologies and ontologies. These four themes are information processing, interactive-constructivism, social constructivism and radical constructivism, and represent various positions along a spectrum of epistemic views ranging from absolutist through evaluativist to relativist (Yore, 2001).

Information processing is the most behaviourist face of constructivism. It represents the belief that students learn mostly from their teacher and their classroom experiences (Henriques, 1997). The classroom is the locus of mental activity with the teacher carefully designing activities that elicit students' prior knowledge and guide them collectively to a common endpoint that represents the views held by experts in the field.

The interactive-constructivist model is a "middle-of-the-road interpretation of constructivism [that] recognizes that contemporary science is based on a hybrid worldview of knowing that stresses the importance of interactions with the physical world and the sociocultural context in which interpretations of these experiences reflect the lived experiences and cultural beliefs of the knowers" (Yore, 2001). This view of knowledge construction posits that learning occurs when the learner is able to interact with the physical world and other people (the public aspect) and these interactions are then combined with prior experiences and understandings to create newer understandings (the private aspect) (Henriques, 1997). Henriques (1997) lists the following attributes of the interactive-constructivist view:

- alignment among outcomes, instruction resources and assessment;
- outcomes of conceptual change, conceptual growth, metacognitive strategic learning;
- does not 'rule' out direct instruction embedded in a natural context of need;

- supports big ideas / unifying concepts (AAAS, 1993; NRC, 1996), science literacy and habits of mind needed to attain scientific literacy;
- requires students to gain ability to construct the constructions, think critically, to communicate their constructions and persuade others of their value or utility;
- encompasses guided inquiry, learning cycles, conceptual change and generative approaches;
- and the teaching involves accessing, engaging, experiencing/exploring, justifying/rationalizing, consolidating/integrating old and new, and applying knowledge (p. 22).

With this view, the teacher is not always the locus of control in the classroom, only becoming so when appropriate. The teacher does not surrender complete control to the students, but takes control as little as necessary to enable the students to direct their learning and make their own way towards new understandings. The following section on the learning cycle more completely articulates this epistemic view and the practices that facilitate it in the classroom.

A social constructivist view holds that knowledge is created and is given legitimacy through social interactions (Staver, 1998). Proponents of social constructivism such as Gergen (1995) focus on the function of language as being the catalyst used to facilitate the construction of new knowledge. Parallels exist between groups of students who work together to share experiences, make observations collectively and put forth explanations to arrive at new understandings and groups of scientists who do much the same within their discipline.

Finally, the radical constructivist view, while not commonly accepted by practicing scientists, is gaining prominence in science education literature (Staver, 1998). This view allows for multiple understandings, all of which are equally valid (Henriques, 1997). Staver (1998) describes a central tenet of this view as the role of cognition to not be used to determine an objective reality, but instead to organize an individual's experiences. New knowledge is created by individuals based on their unique experiences and the diversity of personal prior knowledge. As such, each individual's responses to contradictory information or general observations about phenomena will not be accommodated in the same way as others.

Social and radical constructivism are similar in many ways with the primary difference between them being "their foci of study. In radical constructivism, the focus is cognition and the individual; in social constructivism, the focus is the language and group" (Staver, 1998, p. 505). With both of these views, teachers play a minimal role in guiding students, but rather respond to a groups' or individual student's needs as they arise.

Table 2.1 presents a summary of the major components of each of the four themes of constructivism described.

Table 2.1: A summary of the four themes of constructivism (taken from Yore, 2001)

Feature	**Information Processing**	**Interactive-Constructivist**	**Social Constructivist**	**Radical Constructivist**
Worldview	Mechanistic	Hybrid	Contextualistic	Organistic
Ontological View	Realist	Naïve Realist	Idealist	Idealist
Epistemic View	Absolutist (traditional)	Evaluativist (modern)	Evaluativist (postmodern)	Relativist (postmodern)
Judgment Criteria	Nature as Judge	Nature as Judge	Social Agreement as Judge	Self as Judge
Psychological Locus of Mental Activity	Private	Public and Private	Public	Private
Pedagogical Structure	Teacher	Shared: Teacher and Individuals	Group	Individual
Linguistic Discourse	One-way: teacher to student	Two-way: negotiations to surface alternatives and to clarify	Two-way: leading to consensus	One-way: Individual to self (inner speech)

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While many views of constructivism have been formulated and articulated in the literature (Henriques, 1997), when asked to identify the view that best describes the current, commonly accepted view, the scientific community overwhelmingly tends to choose the interactive-constructivist or social constructivist theme as it best represents the evaluative (modern) epistemology (Yore, 2001).

Criticisms of constructivism

Constructivism is not without its critics. Matthews (2002), for example argues that constructivism has been used as the basis to support a variety of political "reformist programs in education" including multicultural and feminist education along with science and mathematics education. While acknowledging that the theory of constructivism has been helpful in science and mathematics education, by making teachers aware of the importance of prior knowledge, the importance of increased engagement of students in lessons and the human dimensions of science, he asserts that many other philosophies espouse these views as well.

Constructivist teaching

Not to be confused with constructivism is constructivist teaching, also commonly referred to as teaching through 'inquiry'. While constructivism is an epistemology that allows students to better understand the world around them, inquiry learning is the set of ideal practices and conditions that facilitate learning (Colburn, 2000). These practices include:

1. Emphasizing process skills such as "observing, inferring, and experimenting. Inquiry is central to science learning. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations." (NRC, 1996, p. 2)
2. Using cooperative learning to enhance students' abilities to collectively evaluate data, negotiate meaning, and communicate results.
3. Using questioning strategies that probe students' prior knowledge and experiences to make connections to new knowledge. The appropriate use of wait time is also important because many of these questions will require more time for thought than do knowledge recall questions.
4. Providing demonstrations that either provide discrepant events to challenge students' prior knowledge or to provide opportunities to make

predictions. These demonstrations allow students to practice their process skills and teachers to get a sense of the students' prior knowledge and potential misconceptions.

5. Judicious use of textbooks and lectures to provide small pieces of content knowledge at appropriate times.
6. Using authentic assessment techniques in an effort to get students to evaluate their own knowledge and understanding. (Colburn, 2000)

All of these activities are those that facilitate the building of new knowledge using prior knowledge and experiences but also are used to refine processes that will help them make new knowledge outside of the classroom.

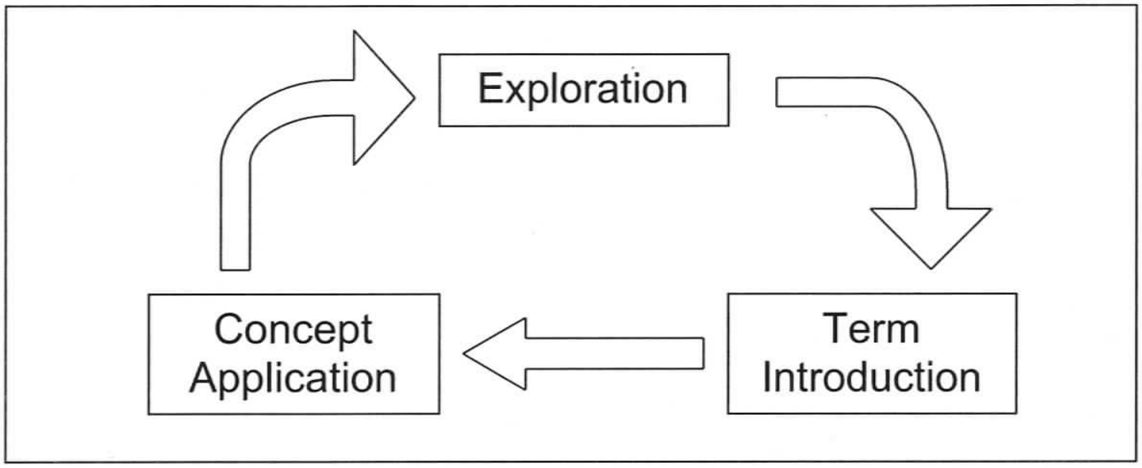
The Learning Cycle and Related Research

Introduction

Perhaps the best way to articulate the relationship between constructivism and inquiry is to describe an instructional strategy that embodies the ideals of both. A comprehensive description and justification of the learning cycle as a superior, inquiry-based approach to teaching both declarative and procedural knowledge was published in 1989 as a monograph for the National Association for Research in Science Teaching (NARST) (Lawson, et al., 1989).

The learning cycle is simply a sequence of instructional activities that allows students to make observations, formulate hypotheses, and make predictions about a particular topic. The learning cycle can contain a number of activities or "phases" – the original NARST monograph contained three phases, 'exploration' where data are presented to the students or a discrepant event is demonstrated and observations are made, 'term introduction' where the concept is articulated and terms used to describe patterns or events are introduced, and 'concept application' where the new knowledge that has been constructed during the previous two phases can be tested in new situations which may, in turn, lead to new explorations (See Figure 2.1).

Figure 2.1: Learning Cycle as proposed by Lawson, et al. (1989*)*



The strategy is based on arguments listed in the previous section – that effective instruction has some essential elements that are required to improve both types of knowledge:

- Questions should be raised or problems should be posed that require students to act based upon prior beliefs (concepts and conceptual system) and/or prior procedures.
- Those actions must lead to results that are ambiguous and/or can be challenged/contradicted. This forces students to reflect back on the prior beliefs and/or procedures used to generate the results.
- Alternative beliefs and/or more effective procedures should be suggested.
- Alternative beliefs and/or the more effective procedures should not be utilized to generate new predictions and/or new data to allow either the

> change of old beliefs and/or the acquisition of a new belief (concept) (Lawson, et al., 1989, p. 45).

Different types of learning cycles

The authors of the NARST monograph (Lawson, et al., 1989) acknowledge that one method would not be able to be applied to all concepts and might not be effective for all groups. Thus, three learning cycles are introduced: descriptive, empirical-abductive, and hypothetical-deductive.

Descriptive learning cycles contain an exploration phase where students "discover and describe an empirical pattern within a specific context" (p. 47). This phase is followed by the teacher giving this pattern a name and the class as a whole looking for further evidence of this pattern in nature. This is the learning cycle that requires the least sophistication in terms of the students' mental abilities. No attempt is made to explain the observations that are collected and discussed, only to identify the pattern.

Empirical-abductive learning cycles have the students discover and articulate the pattern. It then continues by allowing the students to attempt to formulate a reason why the pattern exists by generating hypotheses. The teacher guides the discussion through the term introduction phase and guides the students to the most plausible hypothesis. In this period, it is likely that a great deal of students' misconceptions regarding the topic will come out and can be addressed by the teacher. The teacher can then complete the learning cycle by looking for other situations in nature to which the pattern may apply. This learning cycle involves the students using more formal operational thought as they attempt to organize the data, looking for commonalities and rejecting data or variables that do not apply to the problem.

The final learning cycle is similar to the first two where patterns are identified and hypotheses generated. The students then design and conduct experiments in an attempt to confirm hypotheses. Their results during these experiments are discussed and terms applied to the accepted hypothesis. Again, this phase is followed by an examination of where these patterns and hypotheses might apply elsewhere in the natural world.

All three learning cycles share similar features such as providing experiences that cause disequilibrium and allowing students to generate hypotheses and/or use the evidence collected to argue for which one seems to be the most correct, all in an effort to improve students' reasoning skills. Each of the learning cycles does these, but to different extents, depending on the cognitive level of the students. The cycles also offer ample opportunities for students to exercise the practical and mental procedures used by scientists.

History of the learning cycle

The idea of a learning cycle (e.g. concepts being taught using successive phases of inquiry, instruction and application) was already present in the literature prior to the publication of the NARST monograph and studies had been published in the literature documenting early successes. Ward and Herron (1980) used a learning cycle to teach students chemical concepts. They found that short-term use was helpful to students, especially those who were not operating at the formal operational level and that "[l]ong term use of this method would undoubtedly increase its effectiveness". Renner (1982) summarized the traditional methods of science instruction and contrasted them with "Learning Theory B", an unrefined version of the learning cycle. Schools that used this method witnessed dramatic increases in enrollment in science courses, suggesting that students felt more capable and that they would have a higher chance of success.

Soon after these studies were published, more appeared in the literature exploring particular concepts or aspects of this method of teaching. Lawrenz and Munch (1984) explored the effect of student grouping during inquiry learning. Abraham and Renner (1986) varied the order of the three phases of the learning cycle and studied the effects on student learning. They found that different sequences were effective in different situations, such as when a concept was new to the students versus one they had previous experience with. Hawkins and Pea (1987) developed and tested a computer program, INQUIRE, to help students document and organize their thoughts and experiences during inquiry activities. They argued that such software was necessary due to the emerging popularity of inquiry based teaching methods, of which the learning cycle was one. Tobin and Gallagher (1987) examined the effect of "target students", or students who dominate discussion in science classes and make practical management and questioning suggestions for teachers to use during inquiry activities. Renner, Abraham, and Birnie (1988) performed another study on the necessity that all three phases of the learning cycle are used. They found that certain phases alone did an acceptable job and that missing one phase could easily be remedied by expanding the other two. They also concluded, however, that all three phases being present was the most effective method.

Learning cycle research

Following the publication of the NARST monograph, a great deal of literature was published that examined the learning cycle's effectiveness as an inquiry-based teaching strategy and its implications on science teaching and learning in schools. This research, while focused on learning cycles, was reflective of the benefits of teaching science through inquiry.

Lavoie (1989) studied whether childrens' Piagetian stage or their content knowledge had more effect on them being able to make predictions concerning new scientific concepts. In general, he found that students who had a high content knowledge and who were operating at the formal operational level made for better predictors. Interestingly, he did come across some students who were concrete operational and were able to make successful predictions due to a high level of declarative and procedural knowledge. The author's summary concludes that teachers should strive to teach using a problem-solving approach as this seems to be the most effective way to increase students' content knowledge while providing more authentic opportunities for them to reach the formal operational level.

Teachers' abilities to successfully implement learning cycle instruction in their classrooms were studied by Marek, Eubanks, and Gallaher (1990). "The purpose of this study was to examine how degrees of understanding of a theoretical basis associated with a science curriculum program influences the teaching behaviors during the use of those curricula" (p.832). Teachers attended in-service opportunities that "emphasized the Piagetian developmental model of intelligence and its inherent teaching procedure – the learning cycle" (p. 823). After their participation in these sessions, they were evaluated using a number of instruments and classified as having sound, partial, limited understandings of the theoretical framework, or having misconceptions. The participants were then observed as they taught lessons using the learning cycle in their classrooms. Relationships between teachers' understandings of the theoretical underpinnings of the learning cycle were found. Teachers who did not understand fully the psychological basis of the learning cycle were unable to use it effectively and also demonstrated poor questioning techniques.

Marek and Methven (1991) studied the conservation abilities of elementary students taught using the learning cycle versus those who were taught using expository methods. Again, teachers participated in in-service opportunities to learn about the learning cycle. The researchers observed classes to observe and record changes in teacher procedures and characteristics and to measure students' conservation reasoning and use of language when describing objects. This data was then compared to classes where traditional expository teaching methods were used. From tests administered at the start and the end of the school year, it was found that students in learning cycle classrooms increased their conservation reasoning skills by 44% as compared to only 17% in traditional classrooms. Transcripts of student interviews show better abilities to describe objects by students who were taught using the learning cycle. The researchers noticed that "[e]lementary school students in lab-centered science classes were more willing to talk during the structured interviews of this study and therefore achieved higher levels of social transmission, and finally, they experienced science as the discipline is structured and described by scientists" (p. 52).

Barman and Allard (1993) describe the learning cycle as a good method for teaching science at the college level. They speak about the needs of college instructors to change their philosophies of teaching away from the "empty vessel" approach because the research shows that other methods, like the learning cycle, are more appropriate and effective. He notes that a major hurdle in colleges switching to this model of instruction was the "restructuring of class time. To work effectively, "learning cycle lessons must be able to flow from one complete lesson to another" (p. 11).

A paper-based learning cycle to teach organic chemistry at the college level was developed and described by Libby (1995) after finding himself frustrated by students' attitudes towards organic chemistry as being a "bunch of facts". He found that his methodology produced students who achieved equally well on standardized tests, but whose attitudes were greatly improved as compared to students who learning in a lecture-based class. His technique was to assign paper based problems to students where they needed to discover patterns about an organic chemical concept before the class (concept exploration). In class, the students would summarize and articulate these patterns (term introduction). Finally students would apply these patterns to other problem sets or in the laboratory (concept application). A large benefit of this method of instruction was that students' misconceptions are identified early and in context whereas "[w]ith a standard lecture approach, errors in assumed student abilities often are not detected until the first exam and then it may be unclear as to the source of the problems (p. 627).

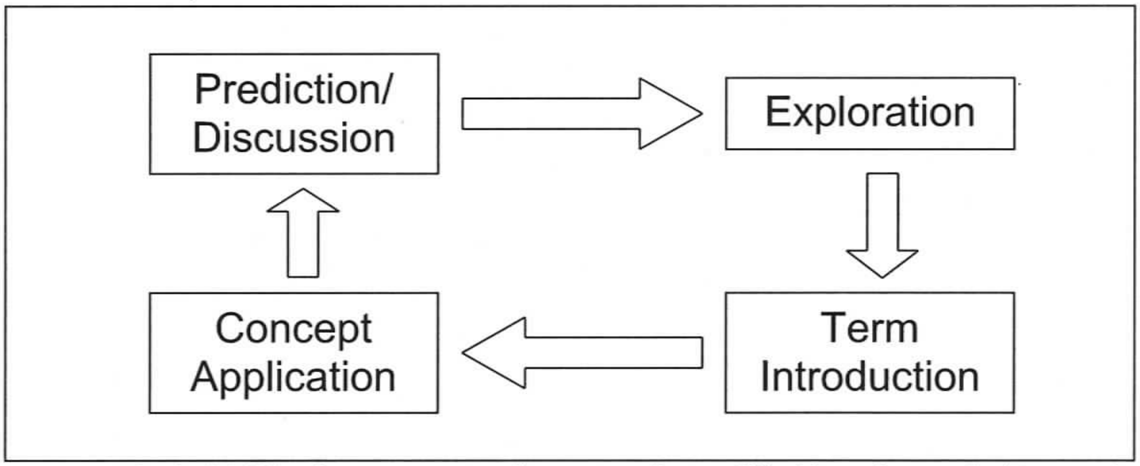
Glasson and Lalik (1993) performed a qualitative study of the use of the learning cycle to facilitate social constructivist learning. This study details the changes in perceptions and attitudes towards teaching and learning by one particular teacher who, after finding herself dissatisfied with her current teaching practice, began to use the learning cycle as her primary method of instruction. Glasson and Lalik's (1993) observations that students were able to more effectively change their conceptions by way of interactions with other students and the teacher led them to develop a Language Oriented Learning Cycle that emphasizes collaborative learning in each of the phases.

Norman (1997) studied Lawson's notions of the role of formal reasoning in science classrooms. Lawson (1992) confirmed that Piagetian tasks were a good indicator of formal reasoning, but what the "essence" of what formal reasoning is still remains unclear. Norman tested Lawson's multiple hypothesis theory that predicts that students with excellent formal reasoning skills will tend to use conditional logic when approaching scientific problems and that this logic is at the basis of hypothetico-deductive reasoning – the improvement of which being a key goal of the learning cycle. Students in high school chemistry were tested using analogs of general logic problems that related to chemical concepts to see if they could identify situations where alternative hypotheses might exist. Norman states that "this study provides further empirical evidence for the multiple hypothesis theory, which can be viewed as a forward step in the construct and validation and elucidation of reasoning" (p. 1080) and proceeds to suggest that teachers should actively attempt to place students in situations where they might have to consider alternative hypotheses to "instill this habit of mind" (p. 1080).

Musheno and Lawson (1999) studied how learning cycles could be represented in textbooks and measured the effectiveness of passages written in the style of the learning cycle. The phases of the learning cycle are arranged so that the term introduction phase occurs after students have had a chance to explore, whereas textbooks usually present new terms and follow them by examples. The authors rewrote passages of text to provide examples of patterns found in nature first which were then followed by the vocabulary, and measured students' comprehension and retention of the information. The results support the authors' predictions although they caution that "the learning cycle-formatted text is preferable to the traditional format, but textbook readings of the concepts still must be used only after these concepts were already experienced and invented by students in a hands-on learning cycle investigation" (p.35).

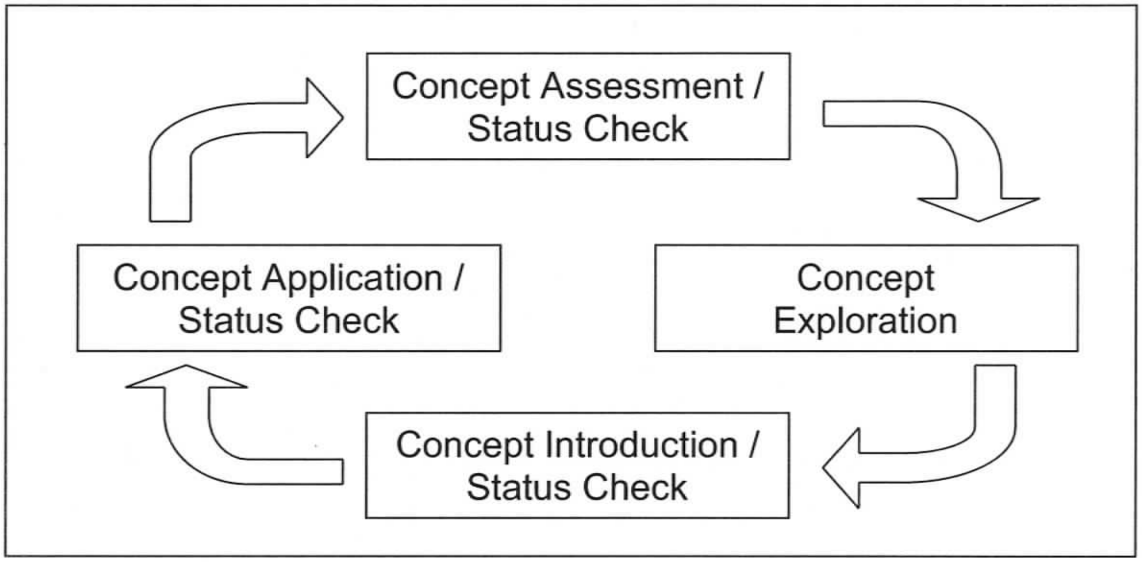
A modification of the learning cycle is proposed by Lavoie (1999) in his paper that suggests adding a new phase before the exploration where students are encouraged to predict the outcome of experiments before performing the experiments themselves (Figure 2.2). This prediction phase helps students reconstruct their knowledge as it often highlights their own pre- or misconceptions that the exploration phase might refute. A trial of this adapted learning cycle in five classrooms found it to be at least equal to, but often more effective to, the traditional learning cycle in teaching biological concepts. Lavoie cautions that for this technique to be successful, teachers must be very well prepared and demonstrate flexibility in the classroom to adapt discussion in such a way to assist students in reconstructing their knowledge.

Figure 2.2: Learning cycle modified by Lavoie (1999)



Blank (2000) advocates a re-refinement of a modified learning cycle (Barman's four-phase cycle that includes an "assessment" stage to identify misconceptions) that she calls a metacognitive learning cycle. This style of inquiry helps prevent "activitymania" and helps teachers become "aware of the important differences between "doing science" and doing science activities" (p. 487). This learning cycle includes "status checks" at every phase where the students and teachers use journaling to track ideas and problems. Using a class doing a three month ecology unit, the researcher observed that this learning cycle did not result in increased understanding of ecological concepts, but did improve retention. She also observed that the success of this learning cycle is very teacher dependent as discussions need to be heavily moderated and probing students for their deeper knowledge or encouraging them to share reflections is often difficult.

Figure 2.3: Metacognitive Learning Cycle (Blank, 2000)



Settlage (2000) studied using the learning cycle approach in the education of preservice elementary school teachers. One aspect he chose to focus on was whether or not it was necessary for a teacher to have a low level of anxiety towards science before he or she could understand and implement lessons using the learning cycle. He found this was not the case – even teachers whose science anxiety levels were high could use the learning cycle effectively. In addition, the self-efficacy level of teachers was measured in the study and, although the author did not want to directly attribute an increase in the self-efficacy level to knowing how to use the learning cycle, his and other studies showed a tenable link.

Baker and Lawson (2001) studied the use of analogies when teaching concepts that involved unseen entities. As has already been established, the ability to understand, apply and create analogies signifies a higher level of thought processes and is used in learning cycle lessons. However, the authors cited studies that have shown that analogies can entrench misconceptions and have little effect on helping students understand concepts. This study measured the effect of using analogies on first-year biology students' content knowledge and attitudes towards genetics. The results supported the prediction that complex analogies helped facilitate the students understanding of theoretical genetics concepts. The authors conclude with a very strong qualifier to their results:

> Nevertheless, in spite of the apparent instructional usefulness of complex instructional analogies and students' generally favorable attitude toward them, their use does not appear to eliminate students' need for higher-order reasoning skills. Unless instruction is designed and conducted to improve students' reasoning skills, instructors can expect many students will remain excluded from full achievement of theoretical concepts and continue to struggle with complex new knowledge (p. 673).

Cavallo and Laubach (2001) explored students' attitude and enrollment decisions to take further science courses beyond grade ten were affected by the learning cycle environment. The authors classified classrooms as either low-paradigmatic (teacher centered, lower levels of inquiry activities, and frequent departures from the ideal learning cycle approach) or high-paradigmatic (student centered, higher levels of inquiry activities, and adherence to the ideal learning cycle structure). They found that the type of classroom students were placed in during the tenth grade did not affect whether or not the student chose to continue in science in later grades – something they attribute to outside factors not considered in the study, such as the students' career aspirations and the state- or college entrance-mandated courses. This was one of the few studies that differentiated between male and female students. It was found that females who enrolled in high-paradigmatic classrooms seemed to be more inclined to take further courses in science and a suggestion to study this aspect further was made. Interestingly, the stereotypical view of science as a male dominated field seemed to be perpetuated in the low paradigmatic classrooms, even in those taught by female teachers.

The nature of the inquiry activities themselves was the focus of a study by Chinn and Malhotra (2002). They argue that many of the inquiry activities that take place in science classrooms have nothing to do with the processes of science and advocate activities that are developed by scientists based on their work rather than those created by textbook authors. Their paper outlines the cognitive processes required by scientists when performing research that should be duplicated by students to develop epistemologically authentic scientific reasoning skills. They cite many activities that are performed in classrooms as being far too simple for students with no opportunities to explore alternative hypotheses or refine the procedures. The authors present some exemplars of inquiry activities that more accurately reflect the cognitive processes mentioned earlier in the paper and also present a general evaluation of many of the popular science inquiry programs.

Palmer (2003) explores the role of texts in an inquiry classroom by using texts to challenge students' misconceptions in order to provoke accommodation or assimilation of new concepts. He chose one ecological concept of all organisms having a role in nature for use in this study. He used texts to present explanations that all organisms have a role in nature. Students who read texts that did not specifically address the misconception that some organisms play no role in society were more likely to continue to harbour this misconception than students who read texts that addressed the misconception directly. His results are so promising that he inserts a number of cautions including that this misconception might not have been so "robust" and, therefore, the students were easily able to accept the correct alterative. In addition, the students may not have been a typical sample due to the novelty of his activity that may have increased their motivation.

These studies highlight the usefulness and effectiveness of the learning cycle as a method of instruction but more importantly, they show the wide ranging consequences of adopting inquiry as the primary strategy for teaching science. Common to all the research on learning cycles is the need to identify students' misconceptions.

Misconceptions

Introduction

Students' prior conceptions of scientific concepts can be a significant barrier in the acquisition of new knowledge. However, inquiry learning requires teachers to identify these conceptions in order to choose an appropriate set of activities to challenge those conceptions. In this thesis, the term misconception refers to an alternative conception that disagrees with the currently accepted view of the science community (Kruger, et al., 1992).

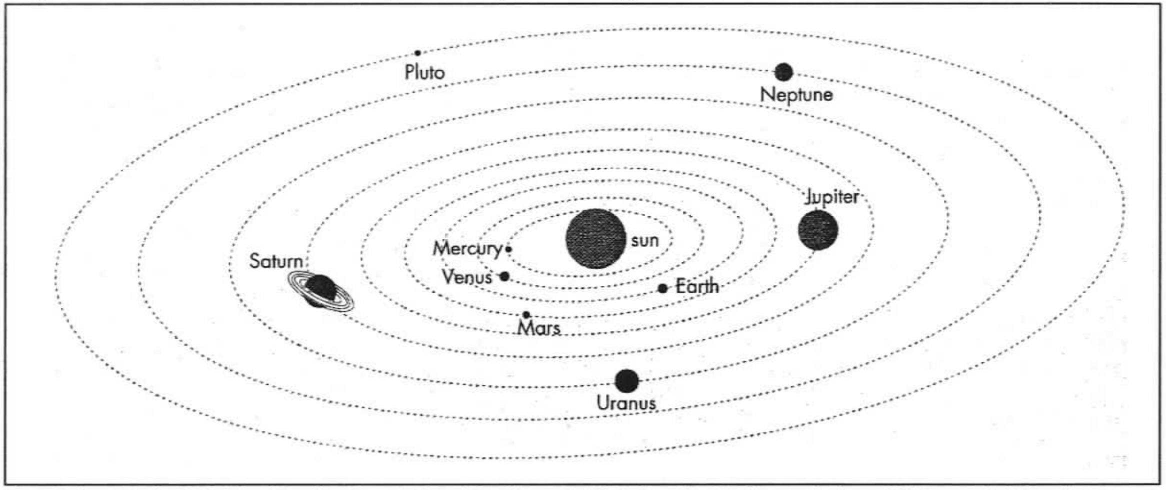
Piaget's large contribution to the development of the constructivist epistemology was his ideas on conceptual change – particularly the notion of accommodation and assimilation (Staver, 1998). Posner, Strike, Hewson, and Gertzog (1982) describe both as methods by which "students using existing concepts to deal with new phenomena", sometimes resulting in situations where students' prior conceptions do not match what they are experiencing – a situation referred to by Piaget as "disequilibration". These particular students were college physics students studying the very advanced concepts of Einstein's theory of general relativity. For the students to first be disequilibrated and subsequently re-equilibrated, the new conception must be intelligible and plausible, the students need to experience dissatisfaction with existing concepts and they should find the new conceptions to be fruitful. Abraham and Renner (1986) studied conceptual change in the chemistry classroom and suggest that learners "assimilate, or transform, data from [their] environment into [their] existing mental structures." and students' mental structures also are changed by that data or, in other words, they accommodate the new information.

Sources of misconceptions

Staver (1998) states "students harbor a wide variety of alternative conceptions about objects and events when they enter formal instruction in science. Moreover, the origins of these alternative conceptions lie in students' diverse personal experiences, which include perception, culture, language, prior teachers' explanations and prior instructional materials. Students hold tenaciously to these alternative conceptions in the face of traditional formal instruction" (p. 517). Staver stresses that traditional instruction does very little to challenge the misconceptions that students have.

Kikas (2004) describes some specific sources of misconceptions. One such source is overgeneralizations of analogies where people make assumptions about one phenomenon based on their experiences with another. A common overgeneralization is where an analogy formed using the macroscopic world is confused with the microscopic world. The common belief that molecules melt when a substance melts and that individual atoms (or molecules) are the colour of the larger body of matter they make up is a specific example of this. An additional example is the common misconception that the seasons are caused by the distance of the earth from the sun because of peoples' everyday experiences with heat sources. A second source of misconceptions is how knowledge is presented in textbooks. An example is the misuse of the word "particle" which has a very different meaning when describing matter from a macroscopic point of view as opposed to describing individual atoms and molecules. Textbooks often contain misleading diagrams such as diagrams of the solar system that shows the paths that planets follow as long ellipses rather than slightly elliptical circles. These diagrams contribute to misconceptions about why the earth experiences seasons and the scale of the solar system as the diagrams do not show the relative placement or relative sizes of the planets to the sun accurately (Figure 2.4).

Figure 2.4: Typical misleading solar system diagram



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Finally, Kikas (2004) cites teacher training as a significant source of misconceptions amongst teachers. Low numbers of required science courses in teacher training programs can cause preservice teachers' prior knowledge about certain topics never to be challenged to expose any misconceptions about science content. Low levels of laboratory experiences or rudimentary laboratory experiences can cause preservice teachers to have misconceptions of how scientists actually work. Finally, preservice teachers' own experiences in science classrooms often set the patterns they will follow to teach science which can result in misconceptions about optimal science teaching practices (Weber, 1999).

Using misconceptions to promote new understandings

In order to reach a state of disequilibrium, two factors must exist: first, these pre- or misconceptions need to exist; and secondly, students need to have experiences that produce data that cause them to question their original conceptions. The fact that many students harbour misconceptions about many topics in the realm of science is well documented (Arnaudin & Mintzes, 1985; Brumby, 1984; Simpson & Marek, 1988;

Wandersee, 1986). The challenge comes with attempting to provide useful experiences that challenge those misconceptions. Traditionally, science has been taught mainly in lectures which, as "a form of passive learning, are insufficient in themselves to create sufficient conflict in students' minds to alter their existing understanding" (Brumby, 1984). Experiencing "anomalies" by way of authentic learning experiences provides students with sufficient conflict to prepare them for and allow them to experience the accommodation of a new conceptual framework (Posner, Striker, Hewson & Gertzog, 1982). Arnaudin and Mintzes (1985) cautions when failing to take students' prior knowledge into consideration when planning instruction, science is viewed as "abstruse, difficult, incomprehensible, and irrational." Arnaudin and Mintzes (1985) conclude their study of using concept maps to promote connections between prior knowledge and new material by stating that a necessary element in the promotion of conceptual change is a non-threatening environment that encourages ideas to be exchanged freely. Wandersee (1986) suggests using the history of a particular scientific concept to document to students how misconceptions are common amongst scientists and evolve as new evidence is discovered.

Identification of misconceptions in students

Students' prior understandings and conceptions must be identified and probed before appropriate inquiry activities can be selected and presented by the teacher. Morrison and Lederman (2003) found a number of strategies that can be used to accomplish this including class discussions, pretests, interviewing, concept mapping, and journaling. Class discussions were seen to be the most widely used technique by teachers of all experiences. As a result, the authors state that questioning strategies employed by teachers must elicit students' responses in such a way that reveals their misconceptions.

Research shows, however, that teachers are not proficient at identifying student misconceptions. Morrison and Lederman (2003) attempted to identify strategies used by teachers to identify preconceptions of scientific concepts. They further attempted to find ways that teachers might use these strategies to adjust their teaching. Four secondary science teachers with varying levels of experience (five to thirty-four years) were interviewed and their classes observed over a nine week period. Each teacher participated in a pre-observation interview prior to observation and a stimulated recall interview afterwards. Each teacher also participated in a final interview at the conclusion of the study. It was found that the primary strategy used by teachers to identify preconceptions was questioning – no alternative strategies such as pretests, concept maps or writing prompts were observed. Questions were classified as to their nature and the teachers' responses to the questions were analyzed. The study mentioned that all teachers had neither a working knowledge of constructivism nor curriculum reform. Morrison and Lederman found that teachers, in general, have a lack of strategies for diagnosing preconceptions, do not sometimes act on diagnosed preconceptions found, and young teachers especially have a lack of knowledge of general preconceptions held by many students.

Barriers to Implementation of Inquiry

Introduction

Regardless of the volumes of research produced that explicate the benefits of inquiry learning, very few students seem to be benefiting from it. "Irrespective of how inquiry has been conceptualized during the past 50 years or so, and conceptions of inquiry have changed during this period, research has consistently indicated that what is enacted in classrooms is mostly incommensurate with visions of inquiry put forth in reform documents…" (Abd-el-Khalick, et al., 2004, p. 398).

Obviously, there must be barriers that exist which result in teachers not choosing to take an inquiry approach in their science classrooms. This section explores some of those barriers that have been identified in the literature.

Wallace and Louden (1992) interviewed a number of elementary science teachers to identify themes that contributed to their choice of classroom practices. Their findings suggest reasons why teachers might be reluctant to adapt towards the use of inquiry. They identified four themes:

1. *What teachers do depends on their biography and experience.* The methods of teaching science that teachers were exposed to during their education were a major predictor of their science teaching practices. Therefore, teachers who were taught in an atmosphere of lecture and low levels of inquiry are likely to continue to use these methods.
2. *Teachers search for comfortable patterns of practice.* Teachers tend to gravitate towards comfortable routines that accommodate their teaching style and lifestyle. The extra time demands of teaching using inquiry can disrupt these routines, causing a teacher to avoid using them. Also, although inquiry is shown to be effective over time, many teachers see "fifteen minutes of effort for five minutes of value" – and are reluctant to give up the "efficiency" of an old routine.

3. *Teachers' knowledge develops gradually and hesitantly.* Teachers tend to change based on immediate classroom problems rather than by social imperatives. If teachers are happy with what is happening in their classrooms, they are unlikely to change.
4. *Teachers' work provides little time for experimentation.* Classroom routines and the demands of a prescribed curriculum make it difficult for some teachers to focus on changing their practices. Elementary teachers also are usually expected to teach other subjects, some of which are seen as more important than science (p 512-517).

Songer, et al. (2003) and Windschitl (1999) list some of the commonly cited systemic reasons explaining the low use of inquiry methods. They list the pressure to perform well on high-stakes standardized tests which, because they are often so content-heavy, leads teachers to believe that they cannot slow the instructional pace down and risk not covering the entire curriculum. Secondly, many schools lack the resources and infrastructure to facilitate hands-on activities, field trips, and laboratory experiments. As a result, the researchers posit that most research on inquiry learning has been done in privileged schools with teachers who are less afraid to take risks. Finally, they suggest that "[s]cience educators and researchers often hold a narrow, somewhat idealistic representation of scientific inquiry as "the kinds of thinking that scientists engage in" or other poorly defined constructs, in part, because few other models, and few well-defined models, of science inquiry exist." (Songer, et al., 1995) These idealized but poorly defined constructs are often reflected in the attempts by textbook companies and curriculum developers to package inquiry activities for mass consumption. These attempts fly in the face of the goals of inquiry learning, to adapt to students particular needs when they are identified in the classroom. The authors state that teachers should reject the "cookie-cutter" approach and depend on their knowledge and skills to work somewhat autonomously based on the needs of their students.

Teachers' attitudes towards and knowledge of constructivism

A major barrier to the implementation of inquiry methods in science classrooms is teachers' beliefs towards constructivism and inquiry. Beck, et al. (2000) maintain that peoples' beliefs play a large role in the decisions they make. This holds true for science teachers who will implement classroom strategies and make pedagogical decisions based on their beliefs. Beck, et al. (2000) assert that many teachers do not teach in a constructivist fashion because they do not believe it is plausible to teach effectively using inquiry. Some of the factors that may be impeding these beliefs are staff development, planning and class time, and curriculum materials. Teachers find it difficult to maintain beliefs in environments where others do not share those same beliefs; therefore it is imperative to offer professional development that includes modeling these teaching methods to both teachers and administrators to have everyone "on the same page". Many teachers' beliefs are hampered by the concern over a lack of planning and class time that is seen to be necessary for inquiry learning. Finally, textbooks remain the central curricular material used in science teaching and most textbooks do not facilitate active learning approaches. Windschitl (1999) adds that successful implementation of inquiry requires a "culture of constructivism" where all teachers and administrators are aware of and supportive of constructivist teaching practices.

The role of the teacher in an inquiry classroom is one that encompasses a wide variety of skills and knowledge. Many descriptions of inquiry teaching describe the role of teachers as being the “guide-on-the-side” or “teacher-as-facilitator”. Crawford (2000), in a study of an exemplary educator who embraces inquiry learning in his classes, lists the variety of roles a teacher must take on. These include the teacher as motivator, diagnostician, guide, innovator, experimenter, researcher, modeler, mentor, collaborator, and learner. She states that people traditionally assume that the level of teacher involvement is lowest for discovery learning and highest for traditional instruction and poses the question of where teachers who use inquiry-based methods might be placed on this continuum. Her answer is that teachers who use inquiry-based methods do not lie within the range specified above, but actually have even greater involvement than traditional instruction. Obviously, a teacher who uses inquiry-based methods is required to be deeply skilled and committed to make it work in the classroom.

Teacher preparation

Beck, et al. (2000) state that problems with inquiry not being implemented in classrooms may lie in teacher preparation programs where elementary teachers of science usually only take introductory science courses and their views of science are shaped by these courses. They also suggest that undergraduate science courses are probably not taught in a constructivist manner, therefore even those teachers who have taken more science content courses during their undergraduate study may not have been exposed to constructivist teaching styles.

Lederman (in Abd-el-Khalick, et al., 2004) speaks of his frustrations regarding what he sees as a misreading of the reform documents when it comes to implementing inquiry in classrooms. The reform documents in their quest to develop scientific literacy are more concerned with students' understandings *about* inquiry rather than "the perennial stress on *doing* inquiry" (p. 402). However, curriculum documents that have been developed based on the reform documents have focused much more on the latter than the former. As a result, students being taught using inquiry methods have certainly gained knowledge of many of the process skills used by scientists, but still have little understanding *about* inquiry and the nature of science. This is not surprising, as most science teachers have "never experienced authentic scientific inquiry during their education in the sciences or within teacher education programs" (p. 404). Lederman predicts that until teachers are more adequately prepared to teach about inquiry, the goals of the reform documents will not be met.

Guziek and Lawson (2004) describe one possible solution to the problem of low teacher content knowledge of science concepts and a lack of awareness of the common misconceptions. Their motivation was their belief that the low number of science courses that prospective elementary teachers are expected to take is problematic as those teachers are expected to teach a wide variety of topics from all the natural science areas. Their solution was to implement a course in their institution that focused primarily on basic science concepts and common misconceptions held by students. They describe having an "epiphany" when they realized that "the lecture-only teaching format used for many content-heavy science courses has effectively screened out students who cannot successfully learn by that style" (p. 38). Consequently, the prospective teachers who had not been "screened out" because they were generally successful in classrooms where traditional teaching methods predominated found it difficult to participate in a class where inquiry was the basis of instruction.

Black (2003) mentions that most prospective teachers have learned science in traditional classrooms based on lecture and limited lab experiences that can decrease their interest in and confidence to teach science. Her research focuses on increasing this interest and confidence by teaching prospective teachers explicitly about the nature of science and having those students design instructional strategies that reflect the nature of science at the same time as introducing new scientific content.

Weber (1999) compares the education of preservice teachers to science students. In the same way that science students harbour many misconceptions that must be identified and challenged in order for them to accommodate a new concept, prospective teachers harbour many misconceptions about how students should be taught science. As an instructor of preservice teachers, she has "begun to think about the problem of preservice teacher preference for direct instruction as a "pedagogical misconception". Like science content misconceptions, [her] students' pedagogical preference for direct instruction is implicit, based on everyday experience, robust, and resistant to change" (p. 9). She concludes by detailing ways that preservice instructors can combat these "misconceptions" and induce preservice teachers to embrace using inductive, problem-solving teaching strategies.

Professional development

Inappropriate or ineffective professional development opportunities offered to practicing teachers may also act as a barrier to the implementation of inquiry. Those teachers who have little or no experience using inquiry may find that professional development opportunities such as workshops and conferences are their only exposure to inquiry practices. Researchers have determined several factors that make professional development more relevant and effective (Darling-Hammond, 1996; Garcia & Ariza, 2004; Loucks-Horsley & Matsumoto, 1999).

Darling-Hammond (1996) and Loucks-Horsley and Matsumoto (1999) offer a variety of suggestions for improving professional development opportunities that are supported by the results of this study. These include:

- *Allowing teachers to tailor a program that addresses their unique situation.* Each school environment and the experiences of individual teachers is different. As a result, teachers are the best resources for determining how to address particular problems and where to direct resources. Simply implementing a district-wide workshop that may address the needs of some schools while not meeting the needs of others will not be successful. Similarly, focusing all professional development opportunities and resources only on certain subject areas may lead to stagnation in others.
- *Avoiding 'one-shot' workshops.* Teachers need sustained professional development that will provide ongoing support as they strive to change toward an increased use of inquiry. Workshops need to gauge and address the needs of the participants and present practical solutions that the group of participants will feel comfortable employing in their classrooms. Once teachers have increased their comfort level, subsequent workshops may then successfully offer more advanced strategies and activities.

- *Encouraging collaborative efforts.* Individual teachers attempting to implement new teaching strategies or activities without the support and understanding of their colleagues will likely lead to feelings of isolation, which may result in discouragement. Professional development should be developed to include groups of teachers who can provide support to each other as new strategies are implemented.

This final suggestion supports Windschitl's (1999) arguments, which specify that to successfully implement inquiry, a culture of constructivism and inquiry in a school must be created with all teachers and administrators within the school knowledgeable about and supportive of constructivist teaching practices.

Garcia and Ariza (2004) also advocate a more gradual approach to professional development, especially when it involves an ultimate goal of "radical and global change" (p. 1243), which would include implementation of inquiry in an environment that predominantly uses traditional teaching methods. In their study of science teachers who were undergoing in-service education, they found similar barriers to Loucks-Horsley and Matsumoto (1999) and Darling-Hammond (1996) that prevented the theoretical aspects of the topics being presented from being put into practice. When participating teachers underwent instruction where the activities did not reflect the teachers' own classroom situations, any radical or global changes on the part of the teachers were not maintained once the teachers returned to their regular classrooms. The authors advocate that professional development opportunities be formulated to take into account the needs and ability levels of the teachers as "only those teachers who are close to the formulation of the content made by the specialist find it easy to establish any meaningful connections, while the rest find it quite difficult" (p. 1243).

International perspectives

Inquiry based science education is not a North American phenomenon. Indeed, many other countries have science education reform documents much like those found in Canada and the United States (Abd-el-Khalick, et al., 2004). Science education researchers in Lebanon, Israel, Australia, and Taiwan are likewise frustrated by the lack of implementation of inquiry learning and have likewise identified possible barriers.

In Lebanon, Boujaoude (in Abd-el-Khalick, et al., 2004) cites the lack of a "clearly formulated philosophy of the nature of scientific inquiry" may confuse teachers as they are unaware of whether they should be teaching science as inquiry or science through inquiry, or both. He also includes high stakes testing and poor curricular resources as major barriers.

Mamlok-Naaman and Hofstein (in Abd-el-Khalick, et al., 2004) relate that Israeli teachers received tremendous amounts of professional development prior to the implementation of an inquiry-based science curriculum that reduced teachers' anxiety and increased their confidence. However, the "enormous" amount of funding this required is at the mercy of the government and could change.

Niaz (in Abd-el-Khalick, et al., 2004) states that Venezuela, like Lebanon, lacks a clearly defined philosophy of inquiry to guide teachers. He also cites arguments relating to disputes over the role of constructivism, the nature of science and inquiry in the process of teaching science and feels there needs to be more agreement before the Ministry of Education will adopt inquiry into science curricula.

Year 12 examinations are a major factor in limiting laboratory and hands-on work in most Australian secondary schools, despite having well equipped labs and support technicians, according to Treagust (in Abd-el-Khalick, et al., 2004). However, primary schools generally do not have the infrastructure to support laboratory experiments and most primary teachers, while having training in science education, lack the confidence to teach using inquiry.

Finally, Taiwanese teachers' "efficiency" beliefs often prevent them from teaching in any way that might jeopardize covering the entire curriculum and thoroughly preparing students for exams, says Tuan (in Abd-el-Khalick, et al., 2004). This seems to be a culturally based barrier based on the population density of the country and the lack of natural resources, making for an intensely competitive environment that prizes efficiency. Therefore, "the 'additional' time needed to engage in inquiry is perceived as less efficient when compared with lecturing about science concepts.

Teachers' misconceptions

In all research that suggests that inquiry teaching is not being widely used, the issues of lack of content knowledge and low awareness of common misconceptions are rarely mentioned. There are studies, however, that specifically have studied the type and number of misconceptions amongst prospective and practicing science teachers.

An early study of misconceptions amongst practicing science teachers at the elementary level was performed by Lawrenz (1986). She stated that, traditionally, elementary teachers are not strong supporters of science education because of their educational backgrounds that are generally weak in the physical sciences and because of the time required to teach hands-on science in their classrooms. She argued that the elementary grades are crucial for learning the basic concepts of science and developing positive attitudes towards science. She administered a 31 item multiple-choice test, originally developed to assess 17 year-old students, to 333 practicing elementary teachers who were representative of the entire population of elementary teachers based on educational backgrounds, years of experience, and current teaching situation. She stated that the sample might be positively biased because the sample was comprised of volunteers who seemed to teach science fairly often. However, she found that the average score was almost identical to the 17 year-old population. She identified a number of specific topics that the teachers had significant misconceptions about including the conservation of mass, electricity concepts, and force and motion. She concludes "elementary school teachers may not have adequate backgrounds in physical science" (p. 659) and because her sample may be positively biased, the actual level of knowledge may even be lower than her study measured. To improve the quality of physical science education, she feels that school districts need to understand the importance of implementing professional development that includes a re-education in the basic physical science concepts. She also argues that these concepts should be presented using concrete experiences that will challenge the teachers' misconceptions.

A study by Kruger, et al. (1992) of English primary teachers specifically focused on the concepts of force, energy, and material changes as these were strongly featured in a new science curriculum document. Over 450 teachers completed a questionnaire and 20 were interviewed to probe their understandings in the three areas. Significant levels of misconceptions were observed and common misconceptions for each topic were specified. Very few teachers had studied physical science beyond secondary school suggesting to the authors that their real-world experiences and observations with the topics were the strongest influences in what they taught their students. Again, the authors suggest professional development for teachers but stress that it should be done in a constructivist manner that offers participants concrete experiences. They also suggest reforms for science education in the training of new primary teachers.

Haidar (1997) in a study of preservice teachers' knowledge of chemical concepts asserted that if teachers had significant misconceptions, it would be unlikely that they would be able to teach those concepts effectively. He found that most of his sample learned chemistry in settings that focused on lecture and memorization of facts and processes. As such, the preservice teachers had limited understandings of the concepts and had difficulty transferring their knowledge to new situations. Haidar concludes with a call for the reform of science teaching at the university level and better developed science education courses.

Schoon and Boone (1998) studied the link between teachers' conceptions of their self-efficacy and any alternative conceptions they may hold. The researchers found that there was no link between the number of alternative conceptions and level of self-efficacy. However, they did find there were certain misconceptions about fundamental concepts that were linked to those with low self-efficacy scores. Schoon and Boone observe that "[d]espite the great amount of work done in the past 20 years to identify common alternative conceptions and to devise means of dealing with alternative conceptions in the classroom, students are still leaving high school and college science courses carrying many alternative conceptions with them" (p. 563). They go on to state that most teachers are not aware of the importance of determining students' prior knowledge to determine which alternative conceptions that students hold and do not plan instruction with this in mind. The authors suggest reforming university science education programs to include courses that address fundamental scientific concepts in a constructivist manner and to teach explicitly common misconceptions and their implications of classroom science teaching practices.

Kikas (2004) in a study of Estonian teachers' conceptions and misconceptions states that for inquiry learning to be successful, teachers "can facilitate this time-consuming and labour-intensive process by… making the preliminary knowledge conscious, explaining and illustrating the new knowledge, helping to establish links between abstract verbal and daily experiential knowledge, and referring to similarities and differences between the everyday and scientific fields" (p.432). She continues by emphasizing the importance of the teachers' grasp of the content knowledge and of common misconceptions:

> In other words, teachers should have a profound scientific understanding of the topic, which enables them to communicate new concepts. Such good and conscious knowledge becomes especially important in using student-centered teaching methods. While in a traditional lecturing situation the teacher may rely only on the textbook. In an [experiment], a discussion, or a group-work situation, she or he must be able to answer various questions and clarify conceptual conflicts.
>
> In addition, teachers should be aware of popular misconceptions in the field and understand the possible reasons for their origin (pp. 432-433).

The importance of the last statement becomes clearer when her article concludes by stating that teachers had a fragmentary knowledge of basic scientific content that impedes the use of inquiry methods in students. Furthermore, a cycle is created where teachers with poor content knowledge or poor understandings of the common misconceptions held by students can teach in such a way as to facilitate the development of those misconceptions in their students.

Purpose

There exists a plethora of research documenting the benefits of using inquiry methods to teach science education. There is also a great deal of supposition within this literature over why inquiry methods are not being implemented in North American classrooms. However, there is no recent research that explores North American teachers' conceptions of scientific concepts in the context of inquiry-based education. This study will contribute to three areas of inquiry research: first, the study expands on current literature about using inquiry to teach science education; second, it explores more deeply a particular reason (misconceptions of scientific concepts held by teachers) why inquiry is not being implemented widely in schools; and finally, it does both of these in the context of the British Columbia school system. This study examines the scientific conceptions and misconceptions held by science educators and their relationships between their demographics, experience, educational background, and choice of classroom teaching practices, a view that is missing from the current literature.

Research Questions

1. What types of misconceptions about science concepts do practicing teachers in British Columbia have?
2. Do connections exist between the number of misconceptions and teachers' educational background, self-assessment of content knowledge, age, years of teaching experience, or classroom practices?
3. Can this information be used to guide teacher preparation programs or professional development opportunities for teachers?

CHAPTER 3

METHODS

Introduction

This study is descriptive research focused on determining the number and types of misconceptions held by upper elementary and middle school teachers of science. It is a mixed method design consisting of quantitative data collected through a paper-based questionnaire followed by qualitative data collected through telephone interviews. Creswell (2005) describes collecting the data in this order the "explanatory mixed methods design". The questionnaires collected teachers' demographic information, a self-assessment of their content knowledge, a survey of classroom practices, and their understandings of selected science concepts. Follow-up interviews were done with selected teachers to more deeply understand their misconceptions and explore any relationships found in the quantitative data. Data were collected from October through December 2005.

This chapter will summarize the design of the study, describe the sample population (including descriptions of the interview participants), discuss and compare teachers in independent schools in British Columbia with those who teach in the public system, describe science teacher education programs in British Columbia universities, describe the instrument developed by this researcher, outline the timeline for the study, and finally summarize its limitations.

Design

Creswell's (2005) *explanatory mixed methods design* was used and "consists of first, collecting quantitative data, and then collecting qualitative data to help explain or elaborate on the quantitative approach" (p. 591). The features of this design include placing a priority on quantitative data collection and analysis, collecting the quantitative data first, and using the qualitative data to refine the results of the quantitative data. This design was deemed ideal for the research problems as the questionnaires allow for a great deal of data to be collected and specific relationships that are subsequently found to be significant or problematic to be explored through the use of interviews. The interviews also served to triangulate the data that was collected through the questionnaires. Priority was given to the quantitative data as results of the quantitative data were more generalizable, due to the larger sample size. The intention of the qualitative data was not to highlight new relationships, but to help explain those found in the quantitative data. The sequence of data collection began with a questionnaire that was mailed out to schools throughout the province. Teachers who responded to the questionnaire were able to indicate whether or not they were willing to participate in an interview. A smaller sample of the questionnaire respondents was selected at random to participate in the interview stage of the research.

Sample

This research took place throughout the province of British Columbia. Packages including information letters and a total of 700 questionnaires (Appendices A & B) were mailed to principals of 207 independent schools throughout the province. Schools were identified using the BC Schools Book (2004), which was obtained from the BC Ministry of Education website. Principals were asked to distribute the questionnaires to teachers of science at the grades five through eight levels in their schools. Schools were sent between one and ten copies of the questionnaire depending on the enrollment for grades five through eight. Six teachers who responded to the questionnaire were contacted and interviewed over the telephone.

Originally, all schools in six public school districts (including independent schools in those districts) were chosen to participate in this research. Due to a provincial teachers' labour dispute, several of the school districts declined to allow this research to take place. Those that did agree to allow the research indicated that the school district would not, however, encourage teachers to participate and advised the researcher that participation rates would likely be very low.

Therefore, the sample in this study was a non-random sample drawn from upper elementary and middle school teachers (gr. 5-8) of science who teach in independent schools in British Columbia. A smaller sample of the teachers who responded and indicated that they would be willing to participate in an interview was selected at random and individually contacted. From this smaller sample, a non-random group of teachers was selected to participate in the interviews in order for a stratified sample of gender, grades taught and years of experience to be represented. Interview participants' anonymity were protected by assigning pseudonyms for any written materials pertaining to them.

Ninety questionnaires were returned by the deadline date. This results in a response rate of 43% based on the number of packages sent out to schools, or 13% of the total number of questionnaires sent. It was not possible to determine how many school principals agreed to distribute the questionnaires to members of their staffs. Several schools (that had each been sent 10 questionnaires and response envelopes) returned their packages to the researcher with a short letter declining to participate. Schools that did not participate and were sent smaller packages may have decided not to assume the expense of mailing the questionnaires back. The total number of questionnaires returned was determined to be large enough to generate viable results. It should be noted that several respondents chose not to answer all questions. Where this is the case, results are calculated based on the data from those who did respond.

Thirty-one males and 54 females reported their gender (n=85), which corresponds to percentages of 36.5 % males and 63.5 % females. Twenty respondents were between the ages of 20 to 29 years; 33 were between 30 to 39 years; 20 were between 40 to 49 years; 14 were between 50 to 59 years; two were over 60 years of age; and one person declined to provide this information. Table 3.1 summarizes the distribution of age groupings.

Table 3.1: Distribution of age groupings

Age Grouping	**Frequency**	**Valid Percentage**
20-29	20	22.5 %
30-39	33	37.1 %
40-49	20	22.2 %
50-59	14	15.7 %
60+	2	2.2 %
Missing	1	

Interview participants

A non-random sample of six teachers was chosen to participate in the interview phase of the research. The participants were chosen to provide a cross section of the teaching population in British Columbia at the grades five through eight levels in terms of gender, teaching experience and educational background. Teachers who were approached to participate indicated their willingness to participate when they completed the questionnaire. Below is a short description of each participant, followed by Table 3.2, which contains a summary of their backgrounds.

Lance is male, 38 years old, with eight years total teaching experience including three years at the grades five through eight level. He holds a BEd degree from a British Columbia university and took four university science courses during his degree, all of which were offered by the education faculty. He is currently a Teacher-on-Call for a non-denominational school, located in an urban area, that offers junior Kindergarten to grade twelve. He has previously worked as a classroom teacher and science department head in Christian and public schools.

Oleg is male, 32 years old, with four years total teaching experience, including three years at the grades five through eight level. He holds a BSc degree and has taken a Post-Degree Professional Program (PDPP) from a British Columbia university, making him eligible for BC College of Teachers certification. He took over 20 laboratory science courses while in university as his degree had concentrations in physics, mathematics, and chemistry. He currently teaches middle school science at a very technology-based school with a "Christian world view", located in a rural setting, that offers Kindergarten through grade twelve.

Annie is female, 40 years old, with approximately 14 years total teaching experience, including eight years at the grade five through eight level. She completed four years of a BEd program at a British Columbia university, after which she was eligible to begin teaching. She does not have a degree, however she holds a Standard Certificate from the BC College of Teachers. She took one earth science course offered by the Faculty of Education. She teaches part-time at a Catholic elementary school, located in an urban area, that offers Kindergarten through grade seven.

Elise is female, 30 years old, with seven years total teaching experience, including one year at the grade five through eight level. She holds a BA, a BEd, and a MEd degree, all from British Columbia universities. She took eight laboratory science courses at the university level. She teaches in a large Catholic school, located in an affluent urban area, that offers two classes of each grade level. She teaches science to both classes at her current grade level while her partner teacher teaches social studies to both classes.

Iris is female, 52 years old, with 20 years total teaching experience, including 15 years at the grade five through eight level. She holds a BSc, a BEd, and a PhD degree, the latter two from British Columbia universities. She gave up a career in research in the field of immunology and began teaching to avoid uprooting her family and to be able to spend more time raising her children. She took 18 laboratory science courses during the course of her university career. She teaches middle school general science and senior chemistry and biology in a non-denominational school, located in an urban area, with a strong academic focus that offers Kindergarten through grade twelve.

Susan is female, 60 years old, with 24 years total teaching experience, all at the grade five through eight level. She completed four years of a BEd program at a British Columbia university, after which she was eligible to begin teaching. She does not have a degree, however, she holds a Standard Certificate from the BC College of Teachers. She took one biology course while in university. She teaches at a Catholic elementary school, located in an urban area, that offers pre-Kindergarten through grade seven. Her school operates on a rotary system where she teaches mathematics and science to various classes.

Table 3.2: Background information of interview participants

Subject	Sex	Age	Total years teaching experience	Years of teaching experience of gr. 5-8	Number of University science content courses taken	Degree(s) or qualifications
L	M	38	8	3	4	BEd,
O	M	32	4	3	> 20	BSc, PDPP*
A	F	40	14	8	1	Std. Cert.
E	F	30	7	1	8	BA, BEd, MEd,
I	F	52	20	15	18	BSc, BEd, PhD,
S	F	60	24	24	1	Std. Cert.

*PDPP = Post-Degree Professional Program

Independent Schools in British Columbia

Funding of schools in British Columbia is administered by two systems. Public schools are wholly funded by grants to school districts and must enroll any student who resides in the district. Independent schools are schools that offer an education that is guided by a particular philosophy and have discretion over which students are enrolled. As such, many of these schools are religious in nature or offer a rigorous academic program designed to prepare students for university entrance. These schools may be partially funded by the Ministry of Education at various levels depending if they meet certain criteria. The more funding the school desires, the more restrictions the school must adhere to (BCMOE, 2005a). Category 1 and Category 2 schools receive partial funding while Category 3 and Category 4 schools receive no public funding whatsoever. All independent schools used for this study were classified as either Category 1 or

Category 2 independent schools, meaning they must meet the following requirements to receive that funding:

- The schools must not, in theory or in practice, promote a doctrine that includes racial or ethnic superiority or persecution, religious intolerance or persecution, social change through violent action, or sedition;
- Their students must meet the specified learning outcomes of the British Columbia curriculum for English Language Arts, Mathematics, Science, Social Studies and French (or another choice of mandatory second language) from Kindergarten - Grade 9. In Grades 10 - 12 all subjects that contribute to British Columbia Certificate of Graduation (Dogwood), must meet the learning outcomes of the British Columbia curriculum (see Ministerial Order 41/91, the Educational Standards Order).
- Independent schools may employ teachers who reflect their schools' various perspectives, but all teachers in certified independent schools must be British Columbia certified; although, in the hiring of staff, or admission of students, independent schools may grant preferences to teachers and students whose religious affiliation matches those of the school (Adapted from BCMOE, 2005a, pg 4).

Approximately 65,000 students are enrolled in independent schools comprising almost 10% of the total student enrollment in British Columbia schools.

Based on these statistics and guidelines, it was determined that teachers in Category 1 and Category 2 independent schools would be a reasonably similar population when compared to all British Columbian school teachers. The only differences that may have to be accounted for are questions about science that may conflict with certain religious beliefs (e.g. evolution) that may be more prevalent amongst independent school teachers due to the religious affiliations of several of the schools.

Science Teacher Education

Qualification

Science educators in British Columbia are generally required to hold a four or five year university degree before gaining certification to teach in British Columbia schools. Two authorities, the British Columbia College of Teachers (BCCT) that certifies teachers for public schools and the British Columbia Ministry of Education (MOE) that certifies teachers for independent schools, grant certification to prospective teachers.

The British Columbia College of Teachers requires that all teachers complete at least a four year (prior to 2000) or five year degree (after 2000) that includes an "acceptable teacher education program" consisting of coursework in educational foundations, planning, assessment, and a practicum experience (BCCT, 2005). The degree must also contain a certain number of units of coursework in an area "related to coursework taught in BC public schools" (BCCT, 2005). A teacher certified by the BCCT is technically eligible to teach any subject at any grade as the college does not issue certificates that specify which subject areas may or may not be taught.

Teachers who wish to teach in independent schools that receive funding from the provincial government are required to hold BCCT certification or be certified by the MOE. The MOE grants unrestricted certification to those teachers who hold teaching credentials from other jurisdictions who do not meet the stringent requirements of the BCCT. The requirements of the MOE are very similar to the BCCT as they require teachers to have "successfully completed a minimum of four years (120 semester credits) of post-secondary studies beyond Grade 12 at a recognized university or college, which includes the equivalent of one year (30 semester credits) of recognized teacher training" (BCMOE, 2005a). However, the MOE may also certify individuals who hold university degrees in specific disciplines who have not completed a teacher training program. These individuals, however, are restricted to teaching only the subjects related to their course of study for their degree.

University Teacher Education Programs

There are several universities or university-colleges that offer teacher training programs in British Columbia. Table 3.3 shows the requirements for an elementary education degree from the three main universities in British Columbia.

Table 3.3: Summary of B.Ed. programs from three BC universities

Feature	UBC	UVic	SFU
Program length in years	5 or 4 + 1*	5 or 4 + 1*	5 or 4 + 1*
Length of practicum	16 weeks	16 weeks	16 weeks
Minimum number of science content courses for admission into program	1	2	1
Number of additional science content courses during program	0	0	0
Number of science methods courses required during program	1	1	0

* 4 + 1 means a completed undergraduate degree followed by (usually) a one-year Post–Degree Professional Program (PDPP)

One can see from the table that the number of science content courses required for admission into an elementary education program is low. Of course, many prospective teachers may take greater number of science courses during their first few years of university or even complete a science degree before returning to take a one-year elementary teacher training program.

Most education programs do not accept students until they have completed at least a year or two of general studies. Once students are accepted into a program, it usually follows an intensive schedule in order to accommodate all the pedagogy and curriculum courses required to meet the BCCT and MOE guidelines for certification, leaving little time for coursework in other areas. Therefore, if a student has met the admission requirements, but finds him or herself lacking in a particular subject area, there often exists no opportunity for them to take additional coursework in that subject area.

Science methods courses

As can be seen from table 3.3 (above), most elementary education students enrolled in a B.Ed. program are required to take only one science education methods course. A typical one-semester course at a British Columbia university involves approximately 30 hours of instruction. EDUC 403, the required course at the University of Victoria is a one-semester course taught using a combination of inquiry, lecture, and practice teaching. The course outline lists the following goals for students:

The student will:

- Define the nature of science and technology, describe the nature of the learner, outline the specific needs of the community and culture of the elementary school, and state how these factors relate to the elementary school science goals, curricula, and instruction;
- Demonstrate the proper use of science applications (processes, skills, thinking strategies, habits of mind) and state how these are learned by children;
- Demonstrate knowledge about, sensitivity toward, and application of elementary school science curricula and instructional resources;

- Develop and apply instructional approaches, teaching strategies, assessment techniques, and support materials that are compatible with the nature of science and technology, the nature of the learner and their [sic] cultural/societal background, along with the IRP outcomes (science content and applications);
- Demonstrate conceptual understanding of the nature of science and technology, major themes, science applications, and specific considerations of elementary school science; [and]
- Demonstrate knowledge about and applications of creative problem solving through a variety of experiences in and outside the classroom, and effective reading and writing to learn strategies in elementary school science (Black, 2005).

As calendar descriptions of the science methods courses offered at other British Columbia universities (Simon Fraser University, 2005; University of British Columbia, 2005) are similar to the one from the University of Victoria, these outcome statements can reasonably be assumed to match those from similar courses offered through other universities.

For some prospective teachers, this course and another 30 hour laboratory science course are all that is required to teach science in an elementary school.

Because teacher qualification in British Columbia allows teachers to teach any grade level, many teachers who are trained for the secondary level often find themselves teaching at the elementary level. Most British Columbia universities do not offer BEd programs for the secondary level, except those that focus on certain subject areas (e.g. music, art, or physical education). Therefore, most teachers who are preparing themselves to teach at the secondary level will complete a four year undergraduate degree with concentrations in the subjects they expect to teach, followed by a (usually) one year PDPP program. The PDPP program includes coursework in topics such as educational planning and administration, evaluation of learning, adolescent psychology, and methods courses specific to the subjects the students have chosen as their specialties. The methods courses that are offered for secondary science students have similar outcomes to the elementary course described above. However, it is conceivable that education students with humanities degrees who receive training only to teach humanities at the secondary level but who find themselves teaching elementary classes, including science, may have never taken a laboratory science or a science methods course.

Instrumentation

The quantitative instrument was a five-page questionnaire that collected demographic data, self-assessment scores measuring content knowledge, measures of frequency of use for classroom practices, and asks respondents to evaluate various "ideas about science" that was developed by the researcher (See Appendix B for questionnaire). The instrument was pilot-tested and submitted to two science education specialists and a research methods instructor for their evaluation in order to establish content validity.

The demographic and educational background data included:

- School District
- Age
- Gender
- Grades taught
- Years of teaching experience
- University degree(s) held
- Number and type of science content courses (not methods courses) taken at the secondary school and university level

Likert-type scales were employed for participants to self-evaluate their own level of science content knowledge and their opinions about the level of science content in teacher preparation programs. A nine-point scale was used for each participant to rate their level of content knowledge as this allowed for a middle response of '5' to represent 'adequate' and enough room for participants to select various levels of 'in-between' responses. Four-point scales were used for the remainder of the questions as they did not allow for a middle response and forced the participants to decide simply if they agreed or disagreed to a certain extent.

A list of classroom practices that covers the spectrum from expository teaching (e.g. reading the textbook in class) to inquiry (e.g. students design and implement their own investigation) was presented and teachers asked to indicate how frequently they employ these practices in their science classrooms.

Misconceptions were evaluated using true/false statements. These statements represent common misconceptions from the four major strands (science processes, life sciences, physical sciences and earth and space sciences) contained in the Integrated Resource Packages (IRP) for the grade levels included in this study (BCMOE, 1996; BCMOE, 2005b). The statements were collected from websites (Beaty, 2005; Fraser, 1995; Operation Physics, 1998; Sweetland, 2005), books (Krebs, 1999; Stepans, 2003) and journal articles (Allchin, 2003; Haidar, 1997; Kikas, 2004; Lederman, 1992; McComas, 1998; Posner, et al., 1982). (See Appendix E for a list of the statements, the correct answers, and their justifications.)

Teachers were asked to complete the questionnaire, enclose it in a plain envelope and return the questionnaire and information sheet by mail using a pre-stamped return envelope.

The qualitative instrument was administered through a telephone interview. The interview protocol was developed using some of the data provided by the questionnaire (Appendix C). A semi-structured format was used. Questions about the teacher's experience, educational background, self-assessment of their content knowledge, usage of classroom practices, knowledge about specific misconceptions, and professional development were asked. In general, the protocol was followed, but if the participant's answers raised an interesting point, it was followed up through the use of unscripted questions.

Timeline and Data Collection

The questionnaire was developed, piloted, and submitted to science education specialists in August. Upon receipt of approval from the human research ethics board, survey packages were assembled and a list of schools finalized. In September, public school districts selected to participate in the study were contacted by telephone and email for approval to carry out the research in the district. Of the six school districts originally contacted, two approved the research but would not encourage teachers to participate, two denied the request, and two, despite repeated phone calls and emails, never responded to the request. Again, the actions of the school districts were likely influenced by the labour dispute.

In the beginning of October, the decision was made to use independent schools throughout the province after it was determined that the population of teachers in independent schools was reasonably similar to those in public schools in terms of qualification and preparation. The survey packages were sent to the principals of each of the schools that enroll students in grades five through eight. The survey package contained a letter of introduction, a contact sheet for indicating whether the participant would be willing to participate in an interview, the survey itself, an envelope to ensure anonymity, and a pre-stamped return mailing envelope. Teachers were asked to complete the questionnaire – a process that was estimated to take only about twenty minutes of the teacher's time – and return it by mail. Data collection using the questionnaire lasted approximately six weeks with a return deadline of November 15, 2005.

Following the quantitative data collection, a random sample of 20 teachers was contacted via email to determine their willingness and eligibility to participate in an interview. From those who responded to the email, a stratified sample of teachers was selected so that an even distribution of grades taught, district sizes, years of experience and educational backgrounds was represented. The interviews were conducted during the last week of November, after the quantitative data was collected, tabulated, and statistical tests performed to provide some basis for the interview questions. The interviews took place over the telephone and lasted approximately 60 minutes. The interviews were recorded and portions transcribed for inclusion in this thesis.

Data Analysis

Data from the questionnaires were entered into a statistical software package to examine relationships within the data to be identified, and to perform statistical tests.

Responses for each of the science ideas were tabulated and expressed as a percentage of the respondents who were correctly able to identify the misconception. The number of correctly identified science ideas by each respondent was tabulated and expressed as a percentage. Finally t-tests and Pearson correlations were performed to compare groups and identify relationships between the demographic data, educational background data, self-assessment of content knowledge, classroom practices and the percentage of correctly identified misconceptions.

The qualitative data was recorded and subsequently transcribed to highlight some of the quantitative results, or in an attempt to explain the quantitative data. Rather than organizing the responses by participant, the data was collated and summarized using individual questions or topics as the major organizers. Where general agreement amongst participants occurred, their responses were paraphrased as a collective response. Individual responses that either contradict the general consensus or were thought to be interesting were also included. No word or phase analysis was used with the qualitative data.

Limitations

There were a number of potential limitations of this methodology. Most important is that the sample was not truly random. Instead, a sample of convenience was drawn from only the independent schools in the province. In addition, the sample may have over-represented teachers who felt confident in their science abilities as teachers who felt less confident likely might be less inclined to participate in a science education study.

The use of short statements that were evaluated as either true or false might not have accurately represented whether the respondent held that particular misconception or not but, instead, reflected the respondent's ability to interpret the statement. The science concepts included in the survey were worded to be as brief and as general as possible, which may cause more confusion than if they had referred to specific situations. Although the instrument was piloted using groups of volunteers, some teachers may have misinterpreted the statements and subsequently indicated an answer that did not correlate with their understanding of the concept.

Finally, the selection of independent school teachers, many of whom teach in schools that present the curriculum with a religious bias, were expected to respond in a biased manner to any questions that deal with topics where religion and science clash, such as evolution and geologic time.

CHAPTER 4

RESULTS

Introduction

Data for this study was collected through two methods: a questionnaire used to collect quantitative data and interviews used to collect qualitative data. The interviews were held following collection and collation of the quantitative data. This chapter will first summarize the quantitative data, which contributed to providing questions that were further investigated through the interviews. Finally, the qualitative data will be summarized.

Questionnaire Data

Gender and Age

Gender and age data is summarized in Chapter 3.

Demographic Data

The school district the teacher taught in was originally meant to be collected in order to measure differences between urban and rural schools. Because independent schools are not part of public school districts, 44.5 % of respondents (n=90) did not include this information on their questionnaire. Data from the remaining respondents indicates that responses did come from all regions of the province, with more responses coming from large urban districts with higher population densities (See Appendix D for data table).

Teaching Experience

With regard to experience at individual grade levels, 52.8 % of respondents reported experience teaching at the grades kindergarten through four levels, 48.3 % reported experience at the grade five level, 44.9 % reported experience at the grade six level, 49.4 % reported experience at the grade seven level, 30.3 % reported experience at the grade eight level, and 30.3 % reported experience at the grades nine through 12 levels. The total teaching experience of the sample ranged from 0 to 30 years. The mean was 10.2 years with a standard deviation of 8.1 years (n=90).

Educational Background

Information was collected to determine the number and type of university degrees held by the respondents, the number of science courses taken at the secondary school level, and the number of science content courses taken at the university level.

The percentages of respondents who held various degrees was as follows: 36.7 % of the respondents held a BA degree; 23.3 % held a BSc degree, 31.1 % held a BEd degree; 4.4 % held some other bachelor's degree; and 14.4 % held a graduate degree. Because some teachers hold more than one type of degree, the percentages sum to greater than 100 %. Table 4.1 summarizes this data.

Table 4.1: Degrees held by respondents

Degree	**Frequency**	**Valid Percentage***
BA	33	36.7 %
BSc	21	23.3 %
BEd	62	68.9 %
Other Bachelors	4	4.4 %
Graduate	13	14.4 %

* Note: Because respondents may hold more than one degree, percentages sum to more than 100%.

Respondents were asked to indicate the number of science courses they took at the secondary school level. At the grade 11 level, 77.8 % respondents had taken Biology; 72.2 % had taken Chemistry; 48.9 % had taken Physics; 13.3 % had taken Geology/Earth Science; and 2.2 % had taken Resource Science/Forestry. At the grade 12 level, 64.4 % respondents had taken Biology; 54.4 % had taken Chemistry; 34.3 % had taken Physics; 13.3 % had taken Geology/Earth Science and 1.1 % had taken Resource Science/Forestry. Table 4.2 summarizes this data. The mean number of secondary school courses taken was 3.8 with a standard deviation of 1.7 (n=90).

Table 4.2: Secondary science courses taken by respondents

Course	**Frequency**	**Valid Percentage**
Biology 11	70	77.8 %
Biology 12	58	64.4 %
Chemistry 11	65	72.2 %
Chemistry 12	49	54.4 %
Physics 11	44	48.9 %
Physics 12	31	34.3 %
Geology/Earth Science 11	12	13.3 %
Geology/Earth Science 12	12	13.3%
Resource Science/Forestry 11	2	2.2 %
Resource Science/Forestry 12	1	1.1 %

Table 4.3 summarizes the number and type of university science courses taken by the respondents. At the university level for biology, 34.3 % of respondents took no courses; 18.9 % took one course; 8.9 % took two courses; 10.0 % took three courses; 1.1 % took four courses; and 26.7 % took five or more courses.

For chemistry, 61.1 % respondents took no courses; 4.4 % took one course; 11.1 % took two courses; 5.6 % took three courses; 8.9 % took four courses; and 8.9 % took five or more courses.

For physics, 63.3 % respondents took no courses; 8.9 % took one course; 20.0 % took two courses; 2.2 % took three courses; 2.2 % took four courses; and 3.3 % took five or more courses.

For geology/earth science, 40.0 % respondents took no courses; 38.9 % took one course; 12.2 % took two courses; 5.6 % took three courses; 1.1 % took four courses; and 2.2 % took five or more courses.

For environmental science, 67.8 % respondents took no courses; 15.6 % took one course; 7.8 % took two courses; 3.3 % took three courses; 3.3 % took four courses; and 2.2 % took five or more courses.

The proportion of respondents who had taken four or fewer university science courses in any discipline was 54 %. The proportion of respondents who indicated they took no science courses while in university was 8.9 %. Overall, the mean number of science courses taken by the sample was 5.7 with a standard deviation of 5.1 (n=90). This figure may be lower than actual because respondents could not indicate the exact number of science courses in any one discipline if the number exceeded five.

Table 4.3: Number of university science courses taken by respondents

	Biology		Chemistry		Physics		Geology / Earth Science		Environmental Science	
	Freq.	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**	**Freq.**	**%**
No Courses	31	34.4	55	61.1	57	63.3	36	40.0	61	67.8
1 Course	17	18.9	4	4.4	8	8.9	35	38.9	14	15.6
2 Courses	8	8.9	10	11.1	18	20.0	11	12.2	7	7.8
3 Courses	9	10.0	5	5.6	2	2.2	5	5.6	3	3.3
4 Courses	1	1.1	8	8.9	2	2.2	1	1.1	3	3.3
5+ Courses	24	26.7	8	8.9	3	3.3	2	2.2	2	2.2
TOTAL	90		90		90		90		90	

Self-assessment and Opinion Questions

Likert-type scales were used to gather a self-assessment of the level of content knowledge needed to teach science at the grade levels being studied and to gather opinions of whether secondary school or university science courses are adequate preparation to teach science.

Respondents were asked to reply to the following statement using a scale of 1 through 9 where 1 meant 'low', 9 meant 'high', and 5 meant 'adequate': "*For the grade level(s) that I teach, I would consider my science content knowledge to be:*". Results are summarized in Table 4.4. Only 5.5 % of respondents chose a score of 4 or less.

Table 4.4: Responses to self-assessment of content knowledge

Response	**Frequency**	**Valid Percentage**
1 (low)	0	0 %
2	2	2.2 %
3	1	1.1 %
4	2	2.2 %
5 (adequate)	22	24.4 %
6	11	12.2 %
7	21	23.3 %
8	17	18.9 %
9 (high)	14	15.6 %
TOTAL	90	

Respondents were asked to reply to the following three statements using a scale of 1 through 4 where 1 meant 'strongly disagree' and 4 meant 'strongly agree'. Table 4.5 summarizes the responses.

"High school science classes provide enough content knowledge to teach elementary/middle school." 43 % of respondents agreed with this statement to some extent.

"Prospective elementary/middle school teachers should be required to take more science ***content*** *(not methods/pedagogy) courses."* While 26.4 % of respondents disagreed with this statement, the majority agreed that prospective teachers should be required to take more science courses.

"Prospective elementary/middle school teachers should be required to take more science ***methods****/pedagogy courses.* While 25.6 % of respondents disagreed with this statement, the majority agreed that prospective teachers need more training in pedagogical content knowledge with regard to science.

Table 4.5: Responses to opinion questions

	High School provides enough content		Prospective teachers should take more content courses		Prospective teachers should take more methods courses	
	Frequency	**%**	**Frequency**	**%**	**Frequency**	**%**
Disagree strongly	7	8.0	0	0	1	1.2
Disagree	43	47.8	23	25.6	21	24.4
Agree	33	36.7	57	63.3	57	63.3
Agree Strongly	5	5.6	7	7.8	7	8.1
TOTAL	88		87		86	

Classroom Practices

Respondents were provided with a list of classroom practices and asked to specify how frequently they use those practices when teaching science. Possible responses included "every class", "frequently, but not always", "occasionally", and "never". Responses were coded in the statistical software as 4, 3, 2, and 1, respectively. Table 4.6 summarizes the frequencies of the responses and the mean score for the top four and bottom four classroom practices as ranked in order of mean score. (For the complete table, see Appendix D)

Table 4.6: Classroom practices employed by science teachers

	Every Class (4)	**Frequently, but not always (3)**	**Occasionally (2)**	**Never (1)**	**Mean**
Listening and taking notes from the teacher	10	48	29	3	2.72
Work in groups	2	60	28	0	2.71
Hands-on activities with specific instructions	5	51	31	0	2.70
Answer textbook or worksheet questions	5	43	38	3	2.56
Take field trips	0	14	70	6	2.09
Write reflections	2	17	51	20	2.01
Design or implement their own investigation	0	12	65	13	1.99
Work on extended science investigations or projects	0	14	57	19	1.94

Misconceptions

Respondents were provided with a list of ideas about science and asked to evaluate the ideas as true or false. Responses were entered into the statistical software as either correct, incorrect, or non-response. All percentages are calculated with non-responses omitted from the totals. The percentage of correct responses for all statements by each respondent had a range of 52.9 % with a minimum of 41.2 % and a maximum of 94.1 %. The mean percentage amongst all respondents was 71.5 % with a standard deviation of 12.5 % (n=90).

Comparisons and correlations between demographic data, teaching experience, and educational backgrounds will be explored in further detail in the next section.

Table 4.7 lists the ideas where fewer than 50% of the respondents indicated the correct answer. Table 4.8 lists the ideas where greater than 90 % of the respondents indicated the correct answer. See Appendix D for the complete list.

Table 4.7: Ideas with fewer than 50 % correct responses

CO*	Idea	% Correct
NSP	Einstein was a poor student in school because he had learning disabilities. (F)	25.0
ESS	The water drains in the opposite direction down the drain in the southern hemisphere. (F)	31.1
ESS	The phases of the moon are caused by the shadow of the earth being cast on the moon. (F)	33.7
PS	Heat from the oven or stove is required to initiate a chemical reaction when cooking. (F)	38.2
NSP	Hypotheses develop into theories and, finally, into laws. (F)	38.6
PS	Electrons surround the nuclei of atoms in well-defined orbits. (F)	40.2
PS	The speed of a pendulum will change if the weight of the bob is increased or decreased. (F)	46.6

(CO=Curriculum Organizer; LS=Life Sciences; PS=Physical Sciences; ESS=Earth and Space Science; NSP=Nature of Science/Processes)

Table 4.8: Ideas with greater than 90 % correct responses

CO*	Idea	% Correct
LS	If you exercise regularly, you can eat whatever you want and not worry about gaining weight. (F)	98.9
PS	Air and oxygen are the same thing. (F)	95.6
ESS	Continents are constantly moving. (T)	95.6
ESS	The earth revolves around the sun once per year. (T)	95.5
PS	Melting ice is a physical change because no new substances are produced. (T)	94.4
PS	Gases have weight. (T)	93.3
LS/ NSP	A person will get cancer if they smoke. (F)	92.1
LS	A person can be harmed by ingesting too much of a vitamin or mineral. (T)	91.1
NSP	The knowledge base in biology, chemistry and physics is interrelated. (T)	91.0

(CO=Curriculum Organizer; LS=Life Sciences; PS=Physical Sciences; ESS=Earth and Space Science; NSP=Nature of Science/Processes)

Correlations and Comparisons

A focus of this study is to establish connections between the number of correctly identified misconceptions and particular groups of teachers. This section will detail any correlations between distinct groups of teachers and the number of correctly identified misconceptions. It will also compare independent groups to determine if one is more likely to be able to correctly identify misconceptions than the other.

Gender.

An independent samples t-test was performed to determine whether a statistically significant difference between the total numbers of correctly identified misconceptions existed based on the gender of the respondent. The test confirmed a significant difference, $t(83)=4.1, p = .00$ with males correctly identifying more misconceptions than females.

Age and total teaching experience.

A 5 x 1 analysis of variance was used with the age ranges acting as the independent variables and the total percentage of correctly identified misconceptions as the dependent variable to determine if the age of the respondents was a statistically significant factor. No statistically significant differences between any of the groups were found $(p<.05)$. Three independent sample t-tests were used to compare the total number years of teaching experience (cut points of 5, 10, and 15 years) with the percentage of correctly identified misconceptions. No statistically significant differences were found.

Degree(s) held.

Independent sample t-tests were performed to determine if the degree(s) held by the respondent had a statistically significant effect on the percentage of correctly identified misconceptions. No statistically significant difference was found to occur between those who hold BA degrees and all others. A statistically significant positive difference was found to occur between those who hold BSc degrees and all others, $t(88) = 3.2, p =.002$. A statistically significant negative difference was found to occur between those who have a BEd degree and all others, $t(88) = 2.7, p = .01$. No statistically significant difference was found to occur between those who hold another type of bachelor's degree and all others. Finally, no statistically significant difference was found between those who hold a graduate degree and all others.

High school and university science courses taken.

A Pearson correlation was completed to compare the number of secondary school science courses taken and the total percentage of correctly identified misconceptions. A statistically significant positive correlation was found to exist, $n = 90, r = 0.266, p < .011$.

A second Pearson correlation was completed to compare the number of university science courses taken and the total percentage of correctly identified misconceptions. A statistically significant positive correlation was found to exist, $n = 90, r = 0.364, p = .000$.

The connection between the number of university science courses taken and the number of misconceptions was further explored with an independent samples t-test. Respondents who have taken four or more university science courses were compared with those who had taken fewer than four. Four was chosen as the cut-off point as it represents the median number of university science courses taken. Those who took four or more science courses were found to be able to identify significantly more misconceptions, $t(88) = 2.8, p = .006$.

Self-assessment of content knowledge.

A Pearson correlation was completed to compare the self-assessment of content knowledge scores and the total percentage of correctly identified misconceptions. A statistically significant positive correlation was found to exist, $n = 90, r = 0.251, p < .017$.

Classroom practices.

In order to compare the classroom practices to the total number of correct misconceptions identified, it was necessary to create data that could be used as a measure of the respondents' use of inquiry and expository methods. To create a measure of a respondent's use of inquiry methods, the mean of their responses to the use of four classroom practices that are strongly aligned with inquiry was calculated. The four classroom practices were having students a) work in groups, b) perform open-ended activities and labs, c) design and implement their own investigations, and d) work on extended investigations or projects. To create a measure of a respondent's use of expository methods, the mean of their responses to the use of four classroom practices that are strongly aligned with expository teaching was calculated. The four classroom practices were having students a) perform hands-on experiences with specific instructions, b) listen and take notes from the teacher, c) answer textbook and worksheet questions, and d) read from a science textbook in class. These calculated means were then correlated against the percentage of correctly identified misconception statements.

A positive correlation between the usage of inquiry and the total percentage of correctly identified misconceptions would indicate that those who use inquiry methods are more adept at identifying misconceptions. Conversely, a negative correlation between the usage of expository methods and the total percentage of correctly identified misconceptions would indicate that those who use expository methods are not as adept at identifying misconceptions.

A Pearson correlation was completed to compare the measure of usage of inquiry methods and the total percentage of correctly identified misconceptions. A positive correlation was found, however it was not deemed statistically significant at the $p<.05$ level. A second Pearson correlation was completed to compare the measure of usage of expository methods and the total percentage of correctly identified misconceptions. A negative correlation was found however, it was not deemed statistically significant at the $p<.05$ level.

Interview Data

Demographics and Teaching Experience

Two of the interview participants were male and four were female. The mean age of the participants (n=6) was 42 years old, The mean total teaching experience of the participants (n=6) was 12.8 years.

Educational Background

Four of the participants (Lance, Annie, Elise, and Susan) took a generalist elementary or middle grades education program at a British Columbia university. Two of those participants did not complete their degrees, as completion of a BEd was not required to begin teaching in the public school system at the time. Elise subsequently completed a graduate degree with a focus on language and literacy. Lance considered himself to have a science specialty because he took three of the four science content courses that were offered by the faculty of education at his university. In general, with the exception of Lance, this group of generalist teachers did not consider themselves to have a strong background in science.

The other two participants (Oleg and Iris) completed BSc degrees prior to completing a post-degree education program at a British Columbia university. Oleg completed a degree majoring in physics with concentrations in mathematics and chemistry and considered going into industry. He had friends who worked in industry and friends who were teachers and, after observing both, determined that teaching was more suited to his personality. He then enrolled in a one-year post-degree professional program to obtain his teaching credentials. Iris completed a BSc in Australia before moving to Vancouver, British Columbia. There, she completed at PhD in Immunology and worked as a researcher. Her decision to enter the classroom was based on the fact that pursuing high-level research in her field would require her family to leave Vancouver and because she felt, ultimately, that she did not "have the right nature" to be a university level researcher. She then enrolled in a BEd program and obtained her teaching credentials. These two participants were considered by the researcher to have a strong background in science.

Self-Assessment and Opinion Questions

Each of the participants was read the self-assessment and opinion questions and asked, to the best of their memory, to provide the response they provided on the questionnaire. Each participant was then asked to justify their response and was asked some follow up questions.

Self-assessment of content knowledge.

The rating scale that was used to gauge the content knowledge of teachers started at 1 for 'low' and ended at 9 for 'high', with the response of 5 representing 'adequate'. The participants' responses to this question ranged from 4 through to 9. The two participants who had undergraduate science degrees both rated their content knowledge at the 9 level. Those participants who undertook generalist training rated themselves lower. This suggests that those teachers who undertook generalist training have a somewhat lower confidence in their content knowledge. The experience of the participant did not seem to have an effect on the rating. For example, Susan, who was the oldest and most experienced rated herself the lowest at a 4/5 level because she felt that her training was not good in terms of science content and she was not able to choose a specialty when she was in university:

> *I think it would have taken longer [to become more comfortable teaching science]. If I had gone back for my degree, I would have learned a lot more...I think that specializing in certain subjects is a good idea.*

Those participants who responded with a lower level all explained that, prior to teaching a new topic, they had to extensively consult texts, internet resources or other colleagues to develop enough confidence and understanding to teach that topic to the class. Some were frustrated with a current curriculum revision that reduced the number of topics that students were expected to cover each year in order to provide more depth for each topic. Those who were frustrated with the new curriculum changes specified they were uncomfortable with the prospect of having to explore each topic in greater depth:

> *When you only have three topics, you really have to dive in…Definitely you need to have more content background and more knowledge to be able to go that deep. (Elise)*

Each participant was asked to define what he or she felt the term 'adequate' should represent on this scale. On average, the participants felt that 'adequate' meant that a teacher had a basic understanding of the basic concepts in each of the main disciplines to give them confidence in teaching any of the topics that are dealt with at the elementary and middle grade levels. Elise explained that 'adequate' means that teachers understand the material enough to explain it to their students, but do not necessarily have to be able to answer more in-depth questions.

Some of the participants admitted that they find they have to do a great deal of personal research before presenting topics to their students which contradicts them rating themselves as adequately prepared for their grade levels. Iris had a very different response to this question. She advocated for specialist teachers, even at the lower grades and felt that 'adequate' meant that a teacher had basic university training in science, but acknowledged the difficulty in the education system being able to attract these individuals.

High school science classes.

Participants were asked to respond to the statement of whether they felt that secondary school science courses provided enough content knowledge to teach at the grade five through eight level. The possible responses to this statement were "disagree strongly", "disagree", "agree", or "agree strongly". Results were mixed with half of the participants disagreeing to some extent and half agreeing. The most common reasons for disagreement for this statement was that secondary school was a long time ago, that students were not required to take all of the science courses at the secondary school level, that high school courses simply did not provide enough depth of knowledge, and that many students were not interested in science in secondary school and do not begin to actively enjoy it or recognize its importance until they are more mature:

> *High school could have been a long time ago...You don't even necessarily even need to take all the subjects and I just don't think enough of the content is taught in high school courses for teachers [to have enough]...I hated high school and wasn't really motivated... I didn't try at all in high school and didn't really get a lot out of high school – got very low grades. (Lance)*

> *"[T]he time between a person taking high school to the point when they're teaching, I don't see how there would be any passion or excitement that would carry forward...They're relying upon distant memories. (Oleg)*

Common reasons amongst those who agreed with the statement were that the depth of knowledge required to teach elementary school science was not really that great, that the depth of knowledge obtained in secondary school science courses was adequate, and that elementary school teachers are only required to provide a basic foundation of concepts:

> *At the [levels that I teach at] a lot of the stuff that I was taught myself in high school is sufficient for what the children have to know...In some cases like a simple machine unit, it's more than the students need to know. (Elise)*

Because the quantitative data showed that most respondents felt that secondary school science courses were sufficient, each participant was asked how their experiences in secondary school science courses affect or influence their teaching today. Each participant interpreted this question somewhat differently and a broad range of responses resulted. Lance said that it had no influence because he was very unmotivated in secondary school. Oleg said that the courses and content was not so much as memorable as the teachers and the relationships that teachers and students were able to develop. He said that observing teachers who had a zest for life and a love of learning provided the most impact. Annie said that she took science courses in secondary school out of necessity rather than interest and had no aspirations to become a scientist. She expressed a desire to repeat her secondary school science courses:

> *I like teaching science because I liked science as a student, however, I hated biology...Now that I teach science I wish I could go back and do high school again because I would work harder, listen more, and just not be a teenager! (Annie)*

She had negative impressions of her science teachers as being "dorky" and having a bias against girls taking science. Elise mentioned that her secondary school science courses were taught very much in a lecture style, which she considered to be a bad influence on those who want to teach science. Iris was told by a secondary school teacher not to become a teacher herself because of her nature. She saw a problem with teachers who have very little life experience aside from learning or working in a school setting. She also experienced teachers who were biased against girls excelling in the sciences. Susan remembered that much of what she learned in high school did not apply to the elementary level (e.g. labs) because it was at a higher level than elementary students need. It is interesting to note that none of the participants mentioned specific topics or participants that they became passionate about or found to be memorable at the high school level. These responses did not provide much evidence towards how secondary school experiences could be improved.

Increased content requirements at the university level.

Participants were asked to respond to the statement of whether they felt that prospective teachers should be required to take more science content courses in university. The possible responses to this statement were “disagree strongly”, “disagree”, “agree”, or “agree strongly”. There was general agreement with this statement. Most participants qualified their answer by mentioning that content courses should focus on practical skills and the practical uses of the content as opposed to lecture on theory. Several mentioned that integrating science content courses with information on how to teach these concepts would be most useful. However, Oleg found that too much content knowledge may be a negative factor:

> *I find myself more challenged when I teach middle school courses than when I teach high school courses because after 3rd year and 4th year [of university, the content] is so distant from what I’m teaching in grade eight, I have to step back and kind of revisit [the foundational concepts]…In some ways you might argue that it has hindered me because I can get so caught up in the details…I feel like I am rambling on and am not making any sense to the students.*

Increased numbers of pedagogy courses.

Participants were asked to respond to the statement of whether they felt that prospective teachers should be required to take more science methods/pedagogy courses in university. The possible responses to this statement were “disagree strongly”, “disagree”, “agree”, or “agree strongly”. In general, most participants agreed to this statement with one exception. Those who agreed mentioned that these types of courses provide increased confidence in teaching science on the part of the teacher because they provide strategies, activities and practical knowledge. Oleg disagreed with this statement because he had a negative experience with these types of courses in his teacher training.

He felt they focused too much on 'mumbo-jumbo' and were not very practical. In general, the participants all agreed that the content of these types of courses determines their usefulness. They suggested these courses would be more relevant if they focused more on increasing the comfort level of teachers, techniques for implementing hands-on/inquiry/discovery strategies for use in classrooms, safety guidelines for doing experiments and demonstrations, and focused less on lesson planning and terminology.

> *I tend to think [more pedagogy courses] would be a good idea, but recognize the difficulty of that on top of all the other courses. I think that strengthening their experience with lab-type discovery science would be a real benefit. I think rather than a science content course, [instruction on] how to lead elementary or junior students through discovery type labs [would be better]. My opinion is that science in grades five to eight needs to be lots of fun – lots of hands on experiments, and think those are the things that I would look for middle school teachers to have extra experiences in. (Iris)*

Improving university training.

Each participant was asked how their university experiences might have been improved in terms of better preparing them to teach science. Again, a broad range of responses resulted. Annie and Iris both would have liked to have had more opportunities to participate in hands-on activities and more experiences designed to help them develop strategies for implementing discovery/inquiry activities in their classrooms. Lance would have preferred more practicum experiences, which would allow him the opportunity to experience more feedback on a greater variety of topics and lessons. Elise felt that individual participants and topics are looked at in isolation during methods classes and little time is spent examining the scope and sequence of the curriculum across the grades. She would have appreciated a better understanding of how topics carry across to other grade levels to get a better idea of the amount of depth she needs to aim for. Susan regretted not completing the final year of her BEd degree because that would have allowed her the opportunity to specialize as the extra year allowed for electives to be taken. Finally, Oleg responded to this question in terms of his undergraduate science degree and his PDPP program. He felt that his science degree lacked emphasis on life-long learning in favour of placing a heavy emphasis on getting the 'right' answers to get a better grade. He felt his PDPP program was geared towards weeding out those who wouldn't survive in the classroom and did not provide him a great deal of practical or useful experience. The common theme through all these responses was a wish for university coursework that provides significantly more practical experience and practical knowledge.

Knowledge of Constructivism, Inquiry and Role of Prior Knowledge

Constructivism.

Participants were asked if they were familiar with the theory of constructivism, to provide a working definition if possible, and to make any comments regarding the theory's validity. Three of the participants who were generalists (Annie, Elise and Susan) were completely unfamiliar or thought the term was vaguely familiar, and were unable to provide an explanation or working definition. When the theory was explained as new knowledge being built upon prior knowledge, they generally agreed it to be a good description of how students learn. Lance, Oleg, and Iris, who either had an undergraduate science degree or a science specialty, were able to provide a working definition of constructivism that roughly corresponded to the predominant definition as specified in the literature review section of this thesis. While all of the participants agreed with the theory, several specified additional factors that, in their opinion, influence a student's ability to learn. Lance was hesitant to support the theory of constructivism wholeheartedly, saying simply that he felt there might be other ways that students learn. Oleg felt that a bigger influence on a student's learning was their motivation and desire to learn. He posited that a student who was motivated to learn a topic and who had no prior knowledge about the topic would learn it as well as someone who was motivated and did have prior knowledge. Annie also specified students' attitudes as playing a major role in learning. She felt that students' attitudes are also affected by the teacher's style:

> *Their prior knowledge is important but it's not the only thing that's important…The style of teaching – what you [as a teacher] do – there are some elementary teachers who read a science textbook with their class and then the kids answer questions and that's what they do for the entire year. If I were in a class like that, I don't think I would learn much and I don't think I'd like science that much. So I think it has a lot to do with the style of teaching. Whether you relate it to something they already know or not, if it's boring, it's boring.*

Iris agreed with the theory but felt a major barrier was the unwillingness of many students to take risks in sharing their prior knowledge because of a fear of being 'wrong':

> *I've discovered that when I've investigated what kids know about something before I teach a new unit, I try and get them to brainstorm things they already know, and it seems to be really restricted by their desire to always have the right answers. They feel that science is always based on there being a right answer…They feel they will be marked down for having a wrong guess.*

Inquiry.

Next, participants were asked to provide their conception of inquiry as a method of putting constructivist theory into practice. In general, all participants were able to provide an example or two of a practice that is aligned with inquiry either as a response to this question or as a response to an earlier question. These examples ranged from short brainstorming sessions, having students complete either independently or collectively

KWL charts (**KWL** = what I **K**now, what I **W**ant to know, and what I **L**earned), being given supplies and an open ended problem and asked to experiment, to designing and carrying out full experiments.

> *One of the things we do with our grade seven and eight students is have them develop their own science fair projects. That…is one of the few opportunities they have to come up with a question by themselves, devise an experiment, test that question, and then present it to somebody else. (Iris)*

None of the participants explicitly made the connection of inquiry being the types of activities that facilitate learning through the theory of constructivism.

Role of prior knowledge.

Throughout the interview, participants were asked various questions in different contexts about the role of prior knowledge in terms of how it impacts creating new knowledge. First participants were asked what exposure they had to the role of prior knowledge in their science methods courses during their teacher training. Participants were then asked:

1. What role a student's prior knowledge plays in them being able to learn new knowledge?
2. Can misconceptions can be helpful in learning new knowledge?
3. Where do students obtain prior knowledge of scientific concepts?
4. What are your techniques for ascertaining students' prior knowledge?

In general, all participants reported very little discussion during their teacher training regarding the role prior knowledge plays in creating new knowledge. Four participants (Lance, Annie, Elise, and Susan) reported never discussing this topic or were unable to remember discussing it during their teacher training. Oleg had the most experience with this topic during his teacher training because he signed up for an elective course that dealt specifically with the topic. He also remembered it coming up occasionally in his required science and mathematics methods courses. Iris also recalled the participant being broached once or twice in her required methods courses but only because students specifically brought it up during class discussions.

Next, participants were asked to give their opinion of how prior knowledge impacts students' abilities to create new knowledge. Each was also asked specifically about misconceptions and their role. Lance indicated that prior knowledge is helpful only if it is correct. If correct, new knowledge could be constructed using the prior knowledge as a foundation and could also provide motivation for building further knowledge. Misconceptions, in Lance's opinion, could be helpful, but only if dealt with skillfully. He cited an example of a teacher who could not convince students that "warm" clothes like sweaters or mitts only insulate against heat loss, and do not actually generate heat to become "warm". Despite the teacher's best intentions, the students did not change their conceptions. However, if a skillful teacher can successfully challenge the misconception and replace it with new knowledge, the old knowledge is soundly discarded:

> *I can think of times when they had a misconception, and once they got the [new] idea, then it's like, "Wow, I can't believe I used to think that!"*

Oleg, who had the most experience in his teacher training with the role of prior knowledge, found it difficult to provide a firm answer to how prior knowledge affects new knowledge. He also felt that misconceptions played more of a role at the higher grades. He agreed that misconceptions might play a role in creating stronger new knowledge. He shared a personal experience of when a misconception was destroyed requiring him to establish a new understanding, the resulting new concept was far more secure.

Annie expressed frustration about when students come with misconceptions to her class because she finds them so difficult to overcome. A specific example she provided was elementary students' inability to see cells as 3-D objects. She understood the importance of prior knowledge in terms of helping provide some direction for future instruction, but was unable to give an example of how a teacher might use a misconception to teach a new concept.

Elise described prior knowledge as playing a major role in the acquisition of new knowledge, specifically when students recognize the vocabulary that must be understood to more deeply explore a topic. She felt the biggest contribution of knowing the students' misconceptions lies in providing direction and focus for further discussion and the selection of activities:

> *Their misconceptions can help direct lessons in terms of learning to deconstruct that misconception and look at where the falseness lies.*

Iris provided her observations that students often have two forms of prior knowledge for each topic: their actual understanding and their taught knowledge. She was frustrated by situations where she knows a student still has an understanding that is wrong, despite them being taught otherwise and being able to explain the correct idea in a test situation. Like other participants, she indicated that she uses students' misconceptions to guide her instruction, but does not often attack particular student's misconceptions directly:

> *I try and bring [out] their misconceptions as a way of focusing which direction we will go and try and help them come to the realization that*

> *they're wrong rather than me just going, "No, that's wrong, and that's wrong."*

Susan felt that prior knowledge does not play any role at all in students being able to acquire new knowledge. She felt that a keen student will learn new knowledge regardless of their prior knowledge. She does not experience many students having misconceptions and felt that misconceptions might play a larger role more at the higher grades because younger students do not have as many misconceptions:

> *At the age they're with me, they haven't really developed that many misconceptions. I think that what I teach them, they take to high school, where you might notice [their misconceptions] more.*

Next, the participants were asked to detail where they believe the most of their students' misconceptions come from. Four participants mentioned parents specifically as sources of misinformation. Three participants admitted that teachers probably pass along a fair amount of misinformation. Three participants specified television or other visual media. Siblings, friends were mentioned by one participant. Susan suggested the internet, because so many of her students were comfortable looking up information using the web but had no idea if her students had any strategies for evaluating the reliability of information from websites. Iris, a senior biology teacher, specified some of her students' churches providing misinformation, especially with regard to evolution. None of the participants mentioned personal life experiences with natural phenomena as being a source of misinformation (e.g. observations that feathers fall to the ground more slowly than a rock).

Finally, participants were asked what techniques they use to ascertain their students' prior knowledge, including their misconceptions. A general classroom discussion with the teacher posing open-ended questions was the predominant technique described, and was used by all the participants. Several participants indicated they start a discussion using a demonstration or discrepant event, which they ask students to explain or hypothesize. KWL charts were mentioned specifically by four of the participants. Two participants mentioned using small group discussions or interviews. The remaining responses were varied and sometimes contradictory. For instance, Lance uses pre-tests, while Oleg specifically mentioned avoiding their use but did not elaborate on this comment. Other techniques mentioned by only one participant included brainstorming, mind mapping, writing poetry, and vocabulary lists.

Classroom Practices

Participants were asked to provide a list of classroom practices that they use frequently and specifically asked if there are some practices they employ on a daily basis. Next, they were asked to identify practices that they wish they could do more frequently. In the questionnaire, most teachers reported occasional or frequent use of allowing students to design and implement their own investigations, which is a strong inquiry practice. The participants were asked to describe how they accomplish this. Finally, participants were asked to provide their opinion as to why the data from the questionnaire seemed to indicate more frequent use of traditional methods as opposed to inquiry methods. Specifically, they were asked to suggest some barriers that prevent teachers from implementing inquiry practices.

One noticeable trend was that three of the six participants (Lance, Elise, and Susan) did not report use of a textbook at all when teaching science. All of the three who did not use textbooks reported frequent use of worksheets instead. Those participants who did report using textbooks (Oleg, Annie, and Iris) all mentioned using them infrequently or only as a 'last resort'. Three of the participants (Annie, Elise, and Iris) reported frequent use of having students take notes from the text, chalkboard, or overhead projector. Two of the participants (Iris and Susan) reported regularly having students use the internet for research. Five of the participants reported using hands-on activities frequently with the one exception being Susan who did not use hands-on activities because she did not feel confident. Hands-on activities cited by the participants who used them included students working at stations around the room, activities with specific instructions, games, constructing models, and formal or informal laboratory-type investigations. Two of the participants (Annie and Susan) could not name a practice they used every class, three (Lance, Oleg, and Elise) specified employing class discussion and general questioning every class, and one (Iris) tries to have each student speak at least one time during every class. In general, these results suggested that this group employs inquiry practices a great deal, and supplements them only occasionally with more traditional forms of instruction. These results conflicted with the data provided by the questionnaire.

When asked what types of practices they want to employ more frequently, five of the six participants specified hands-on activities or laboratory activities. Lance and Elise cited a lack of resources as impeding their implementation of more hands-on activities. Annie mentioned that her classroom has no sink, making it difficult to implement or clean up after an activity. Susan admitted to feeling unconfident because of classroom management issues (noise levels and not knowing whether students are actually learning something) and also cited the great deal of time required to prepare for hands-on activities as being a dissuading factor. Oleg, who does a great deal of hands-on activities, felt like he spent too much time giving instructions and wished that he could spend more time talking to individual students and acting as a guide.

Next, the participants described how they allow students to design and implement their own investigations. Lance mentioned having students do science fair projects but interpreted the question to include his willingness to drop the topic at hand and facilitate an investigation for the students if prompted by their questions:

> *I am a very spontaneous teacher. Often, [the students] just come up with a question, and I might have had something completely different planned, but they've asked, "Can we try this or that?" Well, I will almost always just sidetrack whatever I had planned, if they've asked a scientific question.*

Oleg has based his classes around long term projects such as designing the optimal CO_2 powered car or most effective glider. Annie mentioned occasionally providing students with challenges such as designing the lightest structures that can hold 500 grams. Elise does not allow students to design and implement their own investigations and cited a lack of resources and her inability to deal with logistics of students coming up with a variety of results. Iris indicated that she also requires her students to create a science fair project but laments that students often consult books for 'cookbook activities'. She mentioned that she occasionally provides laboratory activities that have very little instruction, but cites safety reasons as why she cannot often allow students to have free reign in the laboratory. Susan declared that she has students do science fair experiments and has students conduct the occasional investigation at home following explicit instructions. In general, science fair projects seemed to be the predominant method teachers use to have students conduct their own investigation, however these investigations might not be entirely self-guided, as suggested by Iris.

Finally, a broad range of responses was gathered when asked to give opinions why traditional methods still seem to predominate in science classrooms. Lance initially quite strongly expressed his opinion that most elementary teachers are "lazy" and will rely on textbooks because it is easier:

> *If all you have to do is say is, "Open the textbook to page 120…and answer the questions" – it's very easy and that's why [many] do it, in my opinion. Far better to give kids some choices…but that takes more work.*

He also mentioned that teachers are often uncomfortable that kids are not always productive when performing investigations. Later in the interview he suggested that accusing teachers of being lazy might be "a bit harsh" and included the lack of resources as also being a barrier. Oleg suggested that many teachers are worried that they will not meet all the learning outcomes that are specified in the curriculum (IRP) if they spend time doing hands-on activities. He also cites a lack of confidence in personal content knowledge on the part of the teacher, being busy, being reluctant to spend the extra time required to prepare for the activities, and reluctance to take risks as other barriers. Annie mentioned the pressures of meeting all the learning outcomes in the curriculum and the fact that activities do not always produce consistent results as reasons why many teachers avoid doing more inquiry. In addition, she cited low levels of background knowledge being correlated with using traditional methods. Elise cited a variety of possibilities including the fact that assessment tests only measure math and language arts and not science as causing increased focus on the former two participants to the detriment of the latter:

> *I think part of it also has to do with resources and the lack thereof. Sometimes, I find that our school is willing to spend more for math or for language arts than for science…Most people say that reading, writing, and arithmetic are the most important things for children to pick up at the*

> *elementary level and part of it has to do with the FSA (Foundation Skills Assessment) results that are posted [on the internet] – no science results are posted.*

She also acknowledged that teachers often teach the way they were taught and assumes most teachers were taught using expository methods. Finally, she also specified the time constraints imposed by the curriculum and her school's schedule that allows for little flexibility in terms of giving students extra time when necessary. Iris also mentioned the time constraints and lack of resources but also specifies safety as being a concern for teachers teaching increasingly larger numbers of students in one classroom. Finally, Susan specified a lack of content knowledge on the part of the teacher along with classroom management issues as being the most probable barriers.

Specific Misconceptions

Each participant was presented with the three most common misconceptions as shown in the questionnaire data and asked to provide their answer. Results are summarized in table 4.9. Each was then asked where they might have learned that information.

Table 4.9: Responses to top three misconceptions of interview participants

Statement	**Lance**	**Oleg**	**Annie**	**Elise**	**Iris**	**Susan**	**Total Correct**
Einstein was a poor student in school because he had learning disabilities. (F)	F	F	F	T	F	N/R	4/5 (80 %)
The water drains in the opposite direction down the drain in the southern hemisphere. (F)	F	F	N/R	F	F	F	5/5 (100 %)
The phases of the moon are caused by the shadow of the earth being cast on the moon. (F)	F	T	N/R	T	F	T	2/5 (40 %)

F = False, T = True, N/R = No response or would not give a definite response.

Several participants admitted being uncomfortable with this line of questioning as they felt they were being “tested”. Several participants also recognized that all of the misconceptions being probed were all worded in such a way that the correct response to all of them was false and used this realization to guide their answers. Their responses indicated that they all understood the wording of the statements in the way they were intended. The researcher was unable to determine the nature of any relationships between specific misconceptions and any other factor through the use of the interviews.

Professional Development

The final part of the interview concerned professional development. Participants were asked if they had access to professional development opportunities with regard to science education, what types of professional development would be beneficial to them, and whether or not increased collaboration between elementary, middle and secondary school teachers would be beneficial.

While all six participants said that they were aware of professional development opportunities in terms of science, their level of access to these activities varied. Elise and Susan both stated that most of the professional development opportunities offered to them are for mathematics and language arts, most likely because of the yearly assessment tests in these areas. Lance said that he facilitates professional development workshops for other teachers and does not attend many himself. Oleg said he is not actively encouraged by his administration to participate in professional development opportunities, but is able to attend them if he chooses. Annie recently attended a weeklong summer “camp” focusing on science education for teachers and suggested that all teachers should participate in this opportunity. Iris has a great deal of access to professional development opportunities and attends many but acknowledged that public school teachers have less opportunities to attend these due to budgetary concerns she does not have at her private school.

The participants were then asked to share their desires for professional development opportunities. Lance noticed a trend in professional development opportunities in terms of science:

> *I find the science [workshops] tend to all be the same. There's someone coming in to do some 'crazy' experiments…you get these flashy ones where people are blowing up all kinds of stuff but the teacher leaves thinking, "That's really neat but I'm not going to be able to do any of that."*

He was tired of seeing these because he feels they are ineffective for a number of reasons including the participant not having access to the resources required to implement the activities and a lack of time on the part of the teacher to prepare the activities. Oleg mentioned liking hands-on workshops and his desire to see more opportunities for teachers to share teaching ideas, but has found these activities to be intimidating in the past. He described a particular experience where a new teacher shared an analogy to teach a physics concept and was strongly criticized by other, more experienced teachers. Annie advocated for any kinds of activities that would increase excitement about the subject matter amongst teachers as she feels that this excitement will transfer to the students. Elise said that she enjoys hands-on workshops but also would like to have an opportunity to discuss in more detail the theory behind the activities that many workshops offer:

> *While I enjoy the hands-on approach where you actually sort of get to become a student in the class and partake in those activities…I'd sort of like to see something that can balance that with a little bit of theory…The experiments that are conducted and the demonstrations that are shown*

> *usually relate to one concept in isolation and they often don't extend into other areas of science, the applications of science, or the connection between one realm of science with another.*

Iris felt it important that teachers keep abreast of current research in science and have opportunities for teachers to better understand how the content they teach at their grade level will be important when students go on to study more advanced concepts. She also felt that teachers from various grade levels should meet and discuss the scope and sequence of the curriculum. Susan said she enjoys hands-on workshops and would attend more if they did not take up so much time. She indicated that she would also like more workshops that focus specifically on curriculum changes and how to best meet the outcomes in the IRP. Apart from several participants advocating more workshops that demonstrate hands-on activities for students, there were no predominant themes suggested by the participants.

The final question of the interview concerned whether or not the participants feel that a good relationship exists between elementary and secondary teachers of science and, if not, how this relationship might be improved. Several of the participants (Lance, Oleg, Annie, and Elise) specifically identified a negative attitude from teachers of higher grades towards teachers of lower grades:

> *What I hear from some of the high school teachers, basically, is "They don't know anything, so you must not have taught it." I'm very offended by that because I think that [the students] may not be able to recall it, but somewhere deep down, they do have…background knowledge…It's scary for elementary teachers when we think we teach it, but then you turn around and tell us they know nothing…rather than, "Hey, why don't you try this?" and working collaboratively. (Annie)*

All six participants expressed a desire to improve the relationship between elementary and secondary teachers. Iris suggested that most teachers do not understand what teachers in other grades are expected to accomplish:

> *I can see how that would be perceived…but some of it is just pure ignorance on both sides. Elementary teachers do not have a chance to see what happens at secondary school, and vice versa…but I think that the majority of grade eight teachers in the high schools of this province don't know what's taught in grade five.*

Oleg suggested that teachers who establish relationships with other teachers at other grade levels probably do not share the types of negative opinions that are often formed out of ignorance. All responses seemed to indicate that creating a collaborative atmosphere amongst teachers from various grades would help improve the overall quality of science education.

CHAPTER 5

DISCUSSION AND RECOMMENDATIONS

Introduction

This descriptive research study was designed to identify relationships between the number and types of misconceptions that practicing science teachers hold and their demographics, amount of teaching experience, educational background, and preferred classroom practices for teaching science. Due to a labour dispute in the public school system, teachers only in independent schools were used as the sample. However, it has been shown that the qualifications for independent school teachers are very similar to those used in the public system. Independent school teachers of science at the grades five through eight level were mailed a questionnaire that gathered data regarding their demographic information, years of teaching experience, educational background, and their preferred classroom practices. Further, they were asked to evaluate various ideas about science to determine whether the respondents could discriminate between true scientific concepts or common misconceptions. The data from these questionnaires was tabulated using statistical software and various relationships were identified. Questions or issues arising from the questionnaire data were followed up through the use of telephone interviews with a selection of the respondents representing a general cross section of the teaching population at the grade five through eight levels.

Respondents to the questionnaire were, in general, younger than the average teacher, had less experience and had much higher levels of science instruction at the secondary school and university level than required for admission to education degree programs at the university level. Because the sample was one of convenience and voluntary, it could be assumed that many teachers who have low confidence in their science knowledge or low commitment towards quality science instruction were less likely to respond to the questionnaire. Therefore, the results may not be an accurate representation of the average British Columbia teacher at the grade levels being studied. The interview participants were individuals who volunteered an hour of their time and may have a higher commitment to improving the quality of science education than the average teacher. In general, these results are more likely to give an indication of the types and number of misconceptions and the classroom practices used by the proportion of British Columbia teachers who are committed to quality science education. It could be assumed that the number of misconceptions held by teachers is probably higher and the use of inquiry practices in science classrooms is probably lower than these results would indicate.

This chapter will analyze the questionnaire and interview data with regard to the literature already reviewed in Chapter 2, discuss the research questions, and make suggestions for reforming teacher education programs and developing professional development opportunities for teachers of science.

Analysis of Data

Demographics

The distribution of male and female questionnaire respondents is thought to be an adequate representation of the teaching population at these grade levels where females tend to predominate. The proportions of male and female teachers at those grade levels roughly matched those specified in an assessment of mathematics and science teachers in British Columbia (BCMOE, 1995).

The proportion of the questionnaire respondents under 50 years of age was 82%, which is not representative of the general teaching population. In 2003, only 62% of British Columbia teachers were under the age of 50 (BCTF, 2004). With regard to teaching experience, the data show a relatively low mean for total teaching experience, which corresponds to the relatively young age of the sample, and again indicates that the sample is not reflective of the total teacher population in British Columbia. It is felt that the questionnaire respondents are a younger than average sample with less than average levels of total teaching experience.

The distribution of experience at the particular grade levels being studied suggests that teachers have experiences at various grade levels rather than teaching one grade for the duration of their career, and reflects the policy of general certification where teachers can freely move from one grade level to another. The lower numbers of respondents who have experience teaching grade eight and above also suggest that elementary teachers are more likely to move to different grades at the elementary school (grades K-7) level than moving up to the higher grades, which is not an unexpected result.

Two of the interview participants were male and four were female, which is representative of the gender distribution amongst grade five through grade eight teachers. The mean age of the participants (n=6) was 42 years old, which is closer to the actual mean age of British Columbia teachers as compared to the mean age of the respondents to the questionnaires. The mean total teaching experience of the participants (n=6) is 12.8 years, which is a relatively low level of experience, especially when compared to the mean age of the participants. Overall, the mix of sex, age, and teaching experience found in the interview participants is thought to be a closer representation of the population of British Columbia teachers.

Educational Background

The large number of BEd degrees held by the questionnaire respondents serves to reassure the researcher that the majority of the sample are qualified teachers. The relatively large number of teachers with a BSc degree may be as a result of independent schools hiring candidates with science backgrounds as specialist teachers. The low number of graduate degrees is reflective of the young teaching population

All of the interview participants are eligible for certification from the British Columbia College of Teachers meaning they would be eligible to teach in the public school system if they so chose. Two of the six interview participants hold a graduate degree, which is more reflective of the general teaching population.

The number of science courses taken in secondary school by the questionnaire respondents is higher than expected. Although only one science course at the grade 11 or 12 level is required for secondary school graduation in British Columbia, these results may reflect the fact that many universities require more than one course in their admission requirements.

The mean number of university science courses taken by the questionnaire respondents is also thought to be high and suggests that the sample has more background knowledge with regard to science than the general teaching population. Since the minimum number of science courses required for general certification is one, the large mean result may serve to inflate the numbers of correctly identified misconceptions as compared to a sample that is more reflective of the general teaching population. Several teachers reported having taken no laboratory science courses in university. As most teacher education programs require at least one laboratory science course, these teachers may represent those granted certification by the BCMOE to teach specific subjects at specific levels because they do not have any teacher training, may have transferred from another jurisdiction that requires no science courses for certification, or are older teachers who entered the profession before a minimum science requirement was imposed.

Self-assessment and Opinion Statements

The high mean on the scale used to measure self-assessment of science content knowledge suggests that the questionnaire respondents are, on average, quite confident in their teaching abilities with regard to science. The small number of respondents who rated their content knowledge as less than adequate also supports this conclusion. While this may indicate that the general teaching population has a high level of confidence, it is thought that high mean may be reflective of the relatively high numbers of science courses taken while in high school and university by the sample. Therefore, this result might be biased by the fact that teachers who would be inclined to participate in a questionnaire such as this may be more confident in their science abilities.

An issue that was explored with the interview participants was the standard that respondents used to determine their response to this statement. Specifically, they were asked what "adequate" represented. Responses included being able to understand a minimum of content to simply meet the curriculum outcomes, the fact that they met or exceeded the minimum science requirements during their training, or they simply had a personal comfort level with the science content. One participant, who was an advocate for science specialists at the elementary level, felt that adequate should mean that the teacher has a science degree.

Almost half of the questionnaire respondents felt that secondary school science courses were adequate preparation for teaching elementary science content. This result suggests that elementary teachers rely a great deal on what they remember learning in secondary school science courses. Presumably, they also rely a great deal on how they remember science being taught at the secondary level, which may influence the teaching practices they choose to use. In general, teachers who feel that secondary school courses provide them with enough content to teach at the elementary level may not feel comfortable teaching without a textbook or allowing class discussion to more deeply explore concepts for which the teacher has only a cursory knowledge gained from a high school course.

Although many teachers felt secondary school science was adequate preparation for teaching at the elementary level, most respondents indicated they felt that prospective teachers should be required to take more science content and science methods courses during university teacher education programs.

Classroom Practices

In general, classroom practices that are considered to be traditional or expository were ranked higher than inquiry methods. Three of the top four classroom practices are traditional (listening and taking notes from the teacher, hands-on activities with specific instructions, and answering textbook or worksheet questions). It could be presumed that the practice of students "working in groups", which is considered to be a social constructivist practice, may simply be allowing them to complete textbook assignments or the hands-on activities collectively. Three of the bottom four responses are inquiry activities (working on extended science investigations or projects, designing or implementing the students' own investigations, and writing reflections).

It should be noted that this is one area where the questionnaire and interview data contradict each other significantly. Most of the interview participants, while occasionally using traditional methods, reported employing inquiry methods a great deal. This corresponds to the assertion that the interview participants are not representative of the general teaching population.

Through the use of interviews, it can be assumed that a great deal of teachers in British Columbia do not have a strong knowledge of the theory of constructivism nor its implications for teaching practices. This seems to be contrary to Matthews' (2002) belief that constructivism is the most dominant influence in science education today. However, Matthews' statement could simply apply to the literature concerning science education and how it is presented in university classes to prospective teachers – not to what is actually occurring in classrooms. It should be noted that all the interview participants, even those who were not familiar with the term constructivism did, through descriptions of their classroom practices and from what the researcher could glean about their philosophies of teaching, generally subscribe to the theory of constructivism, although not in any sort of formalized manner. Certainly, none of the participants were familiar enough with constructivism to recognize that there are various interpretations of the theory that have developed (Henriques, 1997).

The interview participants generally also demonstrated a rudimentary understanding of the types of activities that constitute instruction through inquiry. None of the participants were able to make the connection of inquiry as being a method by which constructivist principles are put into practice in the classrooms. The interview participants also did not see inquiry instruction as being a systemic classroom practice that should pervade all aspects of teaching science. Instead, they saw it as specific activities, very much aligned with those described by Colburn (2000) that are used occasionally as an alternative to the traditional teaching practices.

Certainly the questionnaire data shows that traditional teaching practices are still very pervasive in science classrooms. This finding is consistent with the literature (Black, 2003; Fulp, 2002). However, teaching practices that are considered to be aligned with inquiry were reported to be implemented at least occasionally by the majority of the questionnaire respondents, which the researcher considers to be a positive finding. Also encouraging is data from the questionnaire and interviews that suggest a dissatisfaction with using textbooks and, subsequently, very little reliance on them on the part of teachers. Although not specifically looked for by the researcher, no evidence was found of use of any of the learning cycles described in the literature (Blank, 2000; Lawson, et al., 1989; Lavoie, 1999).

Participants' knowledge of the sources, usefulness, and techniques for identifying misconceptions in students was low, but not unexpected. A study by Morrison and Lederman (2003) showed that teachers with various levels of experience were not knowledgeable about these issues. In particular, the results of this study echoed that of Morrison and Lederman with respect to their findings that teachers generally have a poor understanding of the usefulness of diagnosing students' preconceptions and a poor selection of strategies that can be employed to determine students' preconceptions. Like

Morrison and Lederman, all of the teachers interviewed in this study reported using general classroom discussion as the predominant method for determining students' preconceptions. Two of this study's findings did contradict Morrison and Lederman's findings, namely the fact that most of the teachers were able to determine a variety of possible sources of students' misconceptions and that additional teaching experience did not seem to be a determining factor in teachers' abilities to identify common misconceptions.

The data from the questionnaire show that inquiry is not the predominant instructional method in most science classrooms and supports the literature in this respect (Black 2003; Fulp, 2002). Possible barriers of implementation of inquiry were explored through the use of the interviews. The responses from the interview participants clearly support Wallace and Louden's (1992) findings. The responses from the teachers consistently affirm that what they do in their classrooms is dependent on their educational backgrounds and classroom experiences; they follow comfortable patterns of practice that are affirmed by their colleagues and available resources; their knowledge develops gradually and they tend to change only when an external factor necessitates that change; and they are busy and have little time for experimentation. The responses of the interview participants also support specific barriers mentioned in the literature that include systemic obstacles (scheduling, classroom infrastructure), lack of resources, time pressures exerted on teachers by the curricula or by standardized tests, and a poor knowledge of the theory of constructivism (Abd-el-Khalick, et al., 2004; Beck, et al., 2000; Songer, et al., 2000).

Misconceptions

All of the statements where less than half of respondents were able to correctly identify the misconceptions fell into the curriculum organizers of Nature of Science/Science Processes (NSP), Earth and Space Science (ESS), and Physical Science (PS).

The poor responses to the NSP items support Black's (2003) and Bright's (2001) assertions that many teachers have unclear concepts about the nature of science. The myth of Einstein's lack of abilities as a child is a pervasive myth that falls into the realm of the history of science, which can cloud people's perceptions of how scientists develop and operate (Allchin, 2003). The myth of hypotheses developing into theories and, finally, into laws shows a poor understanding of the basic processes of science (McComas, 1998).

The poor responses for the ESS and PS items may be a reflection of how few teachers have taken university courses in earth science, physics and chemistry. The myth of water flowing the opposite way down the drain is a pervasive myth that has been perpetuated by its inclusion into mainstream television programs and has been passed along unquestioned by many high school science teachers (Fraser, 1995). It is a classic logical fallacy of a well-documented large-scale phenomenon that has simply been scaled down to a smaller size where its effects are outweighed by other factors (shape of the vessel, size and shape of the drain, and molecular motion of the fluids) (Fraser, 1995). The myth of the phases of the moon being caused by the shadow of the earth is caused by a juxtaposition of the concept of eclipses with that of the phases of the moon. It is a well-documented confusion that has been used in other studies of peoples' misconceptions

(Schneps, 1997). The belief that all chemical reactions are exothermic is the root of the misconception about heat being required to initiate a chemical reaction. The notion of electrons surrounding the nuclei of atoms in well-defined orbits often results from textbook illustrations that mix the Bohr model of the atom with the notion of electrons having discrete energy levels (Krebs, 1999). The nature of electrons residing in probability orbitals is a topic that is covered in secondary school chemistry classes, but is difficult for most students to conceptualize. Factors that affect the speed of pendulums is one of the classic Piagetian tasks used to discriminate students as being either at the concrete or formal operational level by testing their ability to control variables (Lawson, et al., 1975). The weight of the bob makes no difference in the period of the pendulum; it is the length of the pendulum that does so.

It is difficult to identify particular curricular strands where respondents were more likely to be able to identify misconceptions. The one exception is the Life Sciences strand which may be a result of biology courses being the highest subscribed courses at the secondary and university levels.

The first statement on the list that was most frequently correctly identified was related to personal health and fitness, a topic that is well understood by many due to personal experience and possibly due to the prominence of this topic in the media and public consciousness. The responses to the statement that a person will get cancer if he or she smokes shows that the respondents have a good understanding of the variety of carcinogenic triggers and the concept of correlation versus causality. Again, the topic of personal fitness and nutrition was probed by the statement of whether people could be harmed by the ingestion of too much of a vitamin or mineral. Most of the respondents seemed to know that nutrients need to be ingested in moderation – too much of certain vitamins and minerals such as iron or zinc can cause serious health problems. One topic that was an exception to the generally good results for the Life Science strand concerned photosynthesis. Only 53.9 % of respondents correctly identified the statement that plants gain mass by absorbing nutrients from the soil as a myth. Plants gain mass from converting carbon dioxide gas from the atmosphere along with water into sugars (Schneps, 1997). The topic of the nature of matter, which falls into the Physical Science strand, seems to be well understood. Respondents recognized that air, being a mixture of gases is different from the single gas of oxygen. They also understood the concept of physical changes not producing new substances as opposed to chemical changes, which do. Finally, they also understood that gases, being matter, by definition have mass (and weight). The Earth Science strand concept of plate tectonics was well understood possibly because British Columbia is an earthquake zone and this topic is covered in detail in the curriculum and regularly makes the news when earthquakes occur. The concept of the earth revolving around the sun once per year was well understood, although the related misconception of the seasons being caused by the proximity of the earth to the sun as opposed to the tilt of the earth was still prevalent (with only 57.3 % of respondents correctly identifying the misconception). Finally, the Nature of Science/Science Process concept of the interrelatedness of the three main disciplines of the natural sciences was well understood by the respondents.

Two ideas were identified by the researcher as being potentially problematic because of possible conflicts with respondents' religious views. These two ideas were "mountains are created rapidly" and "humans and dinosaurs lived on the earth at the same time". Although the vast majority of the respondents correctly identified those statements as being false, several respondents noted on their questionnaire that their incorrect response was as a result of their religious beliefs concerning creationism. Fundamentalist Christians who interpret the bible literally believe that God created the universe in a short period of time and dismiss the fossil evidence that the above-mentioned statements are based on. Because many independent schools have a fundamentalist Christian philosophy, this researcher expected a higher level of incorrect responses than was observed.

The number and types of misconceptions formed the majority of the questionnaire data. Very little literature has explored relationships between the number of misconceptions a teacher is able to identify and other factors such as age, experience, self-assessment of content knowledge, and the classroom practices used. The interview data did not provide a great deal of insight to the specific relationships.

Comparisons and Correlations

Gender does seem to play a role in the identification of misconceptions, but this result could be due to the fact that males have higher average number of university courses $(M=7.1, SD = 5.2)$ than females $(M = 5.3, SD = 5.0)$.

Teachers' age and total years of teaching experience is also not a determining factor in their ability to identify misconceptions. These results counter the logic that as one gains more experience (and becomes older) he or she would encounter more student misconceptions. These results show that teachers are not statistically significantly better at identifying science misconceptions as their teaching experience increases. In other words, a misconception about a particular topic is unlikely to be identified and resolved simply through accumulating additional experience. This finding is contradictory to Morrison and Lederman's (2003) investigation, but supports the findings of Kikas (2004).

Teachers' educational backgrounds do play a role in their ability to identify misconceptions. Teachers who hold BSc degrees are statistically significantly better at identifying the misconceptions when compared to all others, which is probably reflective of the number of science courses taken by holders of these degrees. Generalist teachers, who are more likely to hold BEd degrees are not statistically significantly better at identifying the misconceptions when compared to all others which may reflect, amongst other factors, the low number of required science courses, the inability to specialize or choose electives in areas where the teacher might feel weak, or the sheer breadth of content knowledge that a generalist teacher is expected to be familiar with giving science content a lower priority than reading or mathematics. Both the numbers of science courses taken at the high school and university level do have a statistically significant effect on the ability to identify misconceptions.

The respondents to the questionnaire were asked to self-assess their level of content knowledge for their grade level. A statistically significant correlation exists that show those who rated themselves higher being able to correctly identify more misconceptions. This finding may highlight the nature of a teacher's confidence level and their knowledge of science content.

The frequencies with which respondents use either inquiry or traditional teaching methods were compared to the total number of misconceptions. Although there are no statistically significant relationships found, a positive correlation was found between those who used inquiry methods more frequently and the percentage of correctly identified misconceptions, and a negative correlation was found between those who used traditional methods more frequently and the percentage of correctly identified misconceptions. The direction of these relationships remains unknown; whether those who are better able to identify misconceptions are more likely to use inquiry methods or whether the use of inquiry methods exposes teachers to a greater variety of misconceptions.

The science idea statements that each teacher was asked to evaluate were categorized into the four major strands that are found in the British Columbia science curriculum documents. The category that was done particularly poorly was the Nature of Science/Science Processes. This finding supports much of the recent literature that explores students' and teachers' understanding of the nature of science and ways to improve these understandings (Lederman, 1992; McComas, 1999; Bright, 2001; Black, 2003). Poorly identified misconceptions also included a number from Physical Science and Earth and Space Science strands which may be reflective of the relatively lower number of Physics, Chemistry and Geology/Earth Science courses taken at the secondary school and university level.

Finally, the least correctly identified concepts were those that are often featured in the literature or training materials for prospective science teachers (Haidar, 1997; Kikas, 2004; Kruger, et al., 1992; Lawrenz, 1986; Schneps, 1997). Why these particular concepts are so common has not been clearly determined through this study. Interview participants were asked to specify where they remembered learning these concepts and to speculate why these remain common misconceptions, but provided no consistent data.

Implications for Preservice Teacher Education

Preservice teacher education seems to have two aspects: formal and informal. The formal aspect is usually a teacher education program offered by a university that contains coursework focusing on specific subject matter along with coursework focusing on how to best assist students in acquiring content. The formal aspect usually also contains a practicum of varying length for prospective teachers to begin teaching with an experienced teacher nearby who can offer feedback and advice. The respondents to this study did not display a great deal of satisfaction with their formal teacher education experiences, especially as they related to teaching science. Respondents to the questionnaire felt that prospective teachers should take more science content courses and more science methods courses. Interview participants often expressed dissatisfaction with the teaching styles used in university content courses and a similar dissatisfaction with the lack of practical experiences offered by the methods courses. In British Columbia, changes to teacher education programs are difficult to impose as the program contents are regulated by the BC College of Teachers in consultation with the various faculties of education. One specific change that this researcher would advocate is the implementation of a hybrid science content/methods course similar to the type suggested by Guziec and Lawson (2004) who developed a course for general education majors that taught the science content of the school curriculum, presenting each topic using a variety of inquiry approaches. They found that this approach increased students' understandings, resulted in more positive attitudes toward teaching science, and increased retention of scientific concepts. British Columbia universities could combine the one required laboratory science course with the one required methods course to create a course that comprehensively covers all the content an elementary science teacher would be expected to cover while modeling inquiry instruction to prospective teachers. This researcher would also advocate increased collaboration between the faculty of education and the various science departments to improve the quality of instruction in first-year science courses to provide an environment that encourages higher levels of student engagement and employs mechanisms to improve conceptual understanding. A model for this collaboration would be the Physics Education Group at the University of Washington.

The informal aspects of a preservice teacher's education are their experiences outside of the formal university setting. These would include the student's own elementary and secondary school experiences and any life experiences that may contribute to their understandings of and attitudes towards science. This study highlighted the fact that many teachers' secondary school experiences still highly influence how they teach science to their own students. Often these experiences occur long before the decision to become a teacher has been made or even considered by the student. It is important, then, that secondary school teachers are made more aware that many elementary teachers feel that high school science courses are adequate preparation for teaching elementary school science and the secondary teacher's choice of classroom practices may influence how future elementary students are taught.

Implications for Professional Development for Practicing Teachers

This study has shown that teachers are, in general, keen to engage in professional development opportunities with regard to science education. However, general improvements need to be made in the type and quality of the opportunities offered. This section will describe some general guidelines for improved professional development opportunities suggested in the literature and echoed by the interview participants. In addition, specific suggestions for improving teachers' knowledge of the use of students' misconceptions in the building of new knowledge will be made.

Loucks-Horsley and Matsumoto (1999), Beck, et al. (2000), and Garcia and Ariza (2004) all make similar suggestions of conditions that would result in more effective science education professional development, specifically in the areas of constructivism and inquiry. These include ensuring that professional development is long term and suited to the specific needs of the teachers, include administrators, and should be implemented in a manner that models the constructivist strategies for the participants. The interview participants in this study mentioned all of these points when asked for suggestions about how professional development opportunities could be improved.

With regard to the role of misconceptions in an inquiry setting, very few of the interview participants were able to discuss their implications and detail effective strategies for identifying and eliminating them. Several participants did understand the strength of new knowledge that is often created when a misconception has been shown to be false and subsequently replaced with a new understanding. Therefore, this researcher feels it important that prospective teachers be taught specifically about the roles of misconceptions. Understandings of other poorly understood notions, such as the nature of science, have been successfully improved through explicit instruction (Black, 2003; Bright, 2001). In the same way, explicit instruction of the role of misconceptions and techniques used to identify and eliminate them would likely result in an improvement in teachers' abilities to help students build new understandings by making use of students' misconceptions. This explicit instruction should be incorporated into teacher education programs for preservice teachers, but could also be easily implemented in workshops specifically devoted to this topic, or as an addition to those workshops or professional development opportunities dealing with inquiry.

Finally, professional development opportunities can include situations where teachers are simply encouraged to gather and discuss what is occurring in their classrooms and to provide suggestions and support to colleagues. The interview participants stressed the importance of collaborating with other science teachers, especially those who teach other grade levels, in an effort to improve the quality of science instruction. While annual science teacher conventions often serve this purpose, school administrators would be wise to facilitate these types of opportunities within schools or within school districts.

Implications for Future Research

This research highlights the need for further research in the area of teacher training and professional development with regard to teachers' conceptions of constructivism, inquiry, the role of prior knowledge, and the role of misconceptions. Both short term and longitudinal studies that measure the effectiveness of increased explicit instruction of the role of misconceptions, as well as the techniques used to identify and eliminate them, would address the issue of improved preservice teacher education or professional development. Further studies documenting the types and numbers of misconceptions held by elementary school teachers should also be done to verify the high levels of misconceptions held. Attention should be paid towards ensuring a truly random sample to obtain more accurate results. In addition, the use of statements that are simply evaluated as true or false might not provide an accurate representation of teachers' specific misunderstandings – a problem that could be remedied by using individual interviews or open-ended questions on a questionnaire, to allow participants to elaborate to enable the misconceptions to be more deeply probed. Specific attention should be paid to the most commonly held misconceptions in an effort to better identify their origins which will help identify strategies that might be used to further eliminate them.

Concluding Remarks

This study confirms that science educators continue to struggle to implement inquiry effectively into their classrooms as suggested in current research and in reform documents. Increased attention should be directed towards improving teacher education and professional development to increase the amount of inquiry occurring in science classrooms. This researcher is optimistic that the capacity for positive change exists, based on the number of young teachers who were willing to participate in this research to improve teaching practice. Also encouraging is the significant number of respondents who reported at least occasional use of inquiry activities, possibly signifying that we are in a period of transition from the traditional teaching practices towards more inquiry. This shift, if it is in fact occurring, will not continue in a positive direction unless inquiry is continually promoted and modeled to future teachers in teacher education programs, and to practicing teachers through professional development opportunities followed by the necessary support and resources required to implement these reforms in their classrooms.

REFERENCES

Abd-el-Khalick, F., Boujaoude, S., Duschl, R., Lederman, N.G., Mamlok-Naaman, R., Hofstein, A., et al. (2004). Inquiry in science education: International perspectives. *Science Education, 88,* 397-419.

Abraham, M.R., & Renner, J.W. (1986). The sequence of learning cycle activities in high school chemistry. *Journal of Research in Science Teaching, 23,* 121-143.

Allchin, D. (2003). Scientific myth-conceptions. *Science Education, 87,* 329-351.

American Association for the Advancement of Science (1989). *Science for All Americans*. New York: Oxford University Press.

Arnaudin, M.W., & Mintzes, J.J. (1985). Students' alternative conceptions of the human circulatory system: A cross-age study. *Science Education, 69,* 721-733.

Ausubel, D. (2000). *The acquisition and retention of knowledge: A cognitive approach.* Boston: Kluwer.

Baker, W.P., & Lawson, A.E. (2001). Complex instructional analogies and theoretical concept acquisition in college genetics. *Science Education, 85,* 665-683.

Barman, C.R., & Allard, D.W. (1993, May). *The learning cycle and college science teaching.* Paper presented at the Annual International Conference of the National Institute for Staff and Organizational Development on Teaching Excellence and Conference of Administrators, Austin, TX.

Baumann, F., Bullard, J, Deschner, D., Flood, N., Gore, G., Grace, E.S., et al. (1995). *Science Probe 8.* Scarborough, ON: Nelson Canada.

Beaty, B. (2005) *Errors and "science myths" in K-6 science textbooks.* Retrieved August 5, 2005 from http://amasci.com/miscon/miscon.html

Beck, J., Czerniak, C.M., & Lumpe, A.T. (2000). An exploratory study of teachers' beliefs regarding the implementation of constructivism in their classrooms. *Journal of Science Teacher Education*, 11, 323-343.

Black, K.M. (July, 2003) *Helping students become better teachers through explicit instruction on the nature of science.* Paper presented at the Tenth International Literacy and Education Research Network Conference on Learning, University of London, London, England.

Black, K.M. (2005) *EDUC 403 Course Outline* (Available from Dr. Kathie Black, Department of Curriculum and Instruction, University of Victoria, PO Box 3010, Victoria, British Columbia, Canada, V8W 3N4).

Blank, L.M. (2000). A metacognitive learning cycle: A better warranty for student understanding? *Science Education, 84*, 486-506.

Bright, P.G. (2001). *Elementary preservice teachers' beliefs about the nature of science and the influence on classroom practice.* Unpublished master's thesis, University of Victoria, Victoria, British Columbia, Canada.

British Columbia College of Teachers (BCCT). (2005). *Application package.* Retrieved on October 27, 2005, from http://www.bcct.ca/certification/bc_graduates.aspx

British Columbia Ministry of Education (BCMOE). (1995). *The 1995 British Columbia Assessment of Mathematics and Science.* Victoria, BC: Queen's Printer.

British Columbia Ministry of Education (BCMOE). (1996). *Integrated Resource Package: Science 8-10.* Victoria, BC: Queen's Printer.

British Columbia Ministry of Education (BCMOE). (2004). *Public, independent, and offshore schools book.* Retrieved September 15, 2005 from http:://www.bced.gov.bc.ca/schoolbook/

British Columbia Ministry of Education (BCMOE). (2005a). *BC Guide for independent schools: Independent school teacher certification.* Retrieved on October 27, 2005 from http://www.bced.gov.bc.ca/independentschools/bc_guide/teach_cert.htm

British Columbia Ministry of Education (BCMOE). (2005b). *Integrated Resource Package: Science K-7.* Victoria, BC: Queen's Printer.

British Columbia Teachers' Federation (BCTF). (2004) *Age Profile of Teachers and Educators in B.C., September 30, 2003* Retrieved November 22, 2005 from http://www.bctf.bc.ca/ResearchReports/2004td02/report.html

Brown, Theodore L. (2003) *Making truth: Metaphor in science.* Chicago: University of Illinois Press.

Brumby, M.N. (1984). Misconceptions about the concept of natural selection by medical students. *Science Education, 68*, 493-503.

Carin, A.A., Bass, J.E., & Contant, T.L. (2005). *Methods for teaching science as inquiry* (9th Ed.). Upper Saddle River, NJ: Pearson Merrill Prentice Hall.

Cates, B. (2001). Writing case studies: Constructing an understanding of student and classroom. In J.C. Brown, & A. Adams, *Constructivist teaching strategies: Projects in teacher education.* Springfield, IL: Charles C. Thomas.

Cavallo, A.M.L., & Laubach, T.A. (2001). Students' science perceptions and enrollment decisions in differing learning cycle classrooms. *Journal of Research in Science Teaching, 38*, 1029-1062.

Chinn, C.A., & Malhotra, B.A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education, 86, 175-218.*

Colburn, A. (2000). Constructivism: Science education's "grand unifying theory". *Clearing House, 74,* 9-12. (ERIC Document Reproduction Service No. EJ614427)

Council of Ministers of Education, Canada (1997). *Common framework of science learning outcomes.* Toronto: Council of Ministers of Education, Canada.

Crawford, B.A. (2000). Embracing the essence of inquiry: New roles for science teachers. *Journal of Research in Science Teaching, 37*, 916-937.

Creswell, J.W. (2005). *Educational research: Planning , conducting, and evaluating quantitative and qualitative research.* Upper Saddle River, NJ: Pearson Merrill Prentice Hall.

Darling-Hammond, L. (1996). The quiet revolution: Rethinking teacher development. *Educational Leadership, 54* 4-10.

Fara, P. (2002). *Newton: The making of a genius.* New York: Columbia University Press.

Fraser, A.B. (1995). *Bad Coriolis.* Retrieved November 15, 2005 from http://www.ems.psu.edu/~fraser/Bad/BadCoriolis.html

Fraser, B.J. & Wubbels T. (1995). Classroom learning environments. In B.J. Fraser & H.J. Walberg (Eds.), *Improving science education.* Chicago: University of Chicago Press.

Fulp, S.L. (2003). *Status of middle school science teaching.* Chapel Hill, NC: Horizon Research.

Garcia, A.R. & Ariza, R.P. (2004). The difficult relationship between theory and practice in an in-service course for science teachers. *International Journal of Science Education, 26,* 1223-1245.

Gergen, K.J. (1995). Social constructivism and the educational process. In L.P. Steffe and J. Gale (Eds.), *Constructivism in education* (pp. 17-39). Hillsdale, NJ: Erlbaum.

Glasson, G.E., & Lalik, R.V. (1993). Reinterpreting the learning cycle from a social constructivist perspective: A qualitative study of teachers' beliefs and practices. *Journal of Research in Science Teaching, 30*, 187-207.

Good, R.G., Shymansky, J.A., & Yore, L.D. (1999). Censorship in science and science education. In E.H. Brinkley (Ed.), *Caught off guard: Teachers rethinking censorship and controversy* (pg 101-121) Boston: Allyn and Bacon.

Guziec, M.K. & Lawson, H. (2004). Science for elementary educators: Modeling science instruction for childhood education majors. *Journal of College Science Teaching, 33,* 36-40.

Haidar, A. H. (1997). Prospective chemistry teachers' conceptions of the conservation of matter and related concepts. *Journal of Research in Science Education, 34*, 181-197.

Hand, B.M., Prain, V., & Yore L.D. (2001). Sequential writing tasks' influence on science learning. In P. Tynjala, L. Mason, & K. Lonka (Eds.), *Writing as a learning tool: Integrating theory and practice* (pp. 105-129). Dordrecht, The Netherlands: Kluwer

Hawkins, J., & Pea, R.D. (1987). Tools for bridging the culture of everyday and scientific thinking. *Journal of Research in Science Teaching, 24*, 291-307.

Henriques, L. (1997). *A study to define and verify a model of interactive-constructive elementary school science teaching.* Unpublished PhD dissertation, Iowa City, IA: University of Iowa.

Keeves, J & Aikenhead, G. (1995) Science curricula in a changing world. In B.J. Fraser & H.J. Walberg (Eds.), *Improving Science Education.* Chicago: University of Chicago Press.

Kikas, E. (2004). Teachers' conceptions and misconceptions concerning three natural phenomena. *Journal of Research in Science Teaching,* 41, 432-448.

Koch, J. (2005). *Science stories: Science methods for elementary and middle school teachers,* (3rd ed.). New York: Houghton Mifflin.

Krebs, R.E. (1999). *Scientific development and misconceptions through the ages: A reference guide.* Westport, CN: Greenwood Press.

Kruger, C., Palacio, D., & Summers, M. (1992). Surveys of English primary teachers' conceptions of force, energy, and materials. *Science Education, 76,* 339-351.

Lavoie, D.R. (1989). *Effects of prior knowledge and Piagetian cognitive development on the process skill of prediction in the learning cycle.* Detroit, MI: Wayne State University. (ERIC Document Reproduction Service No. ED309078).

Lavoie, D.R. (1999). Effects of Emphasizing hypothetico-predictive reasoning within the science learning cycle on high school student's process skills and conceptual understandings in biology. *Journal of Research in Science Teaching, 36,*1127-1147.

Lawrenz, F. (1986). Misconceptions of physical science concepts among elementary school teachers. *School Science and Mathematics, 86,* 654-660.

Lawrenz, F., & Munch, T.W. (1984). The effect of grouping of laboratory students on selected educational outcomes. *Journal of Research in Science Teaching, 21,* 699-708.

Lawson, A.E. (1992). What do tests of formal reasoning actually measure? *Journal of Research in Science Teaching, 29,* 965-983.

Lawson, A.E., Abraham, M.R., & Renner, J.W. (1989). *A theory of instruction: Using the learning cycle to teach science concepts and thinking skill* (NARST Monograph No. 1). National Association of Research in Science Teaching.

Lawson, A.E., Blake, A.J.D., & Nordland, F.H. (1975). Training effects and generalization of the ability to control variables in high school biology students. *Science Education, 59,* 387-396.

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

Libby, R.D. (1995). Piaget and organic chemistry. *Journal of Chemical Education, 72*, 626-631.

Loucks-Horsley, S. & Matsumoto, C. (1999). Research on professional development for teachers of mathematics and science: The state of the scene. *School Science and Mathematics, 99,* 258-271

Marek, E.A., & Methven, S.B. (1991). Effects of the learning cycle upon student and classroom teacher performance. *Journal of Research in Science Teaching, 28*, 41-53.

Marek, E.A., Eubanks, C., & Gallaher, T.H. (1990). Teachers' understanding and the use of the learning cycle. *Journal of Research in Science Teaching, 27*, 821-834.

Martin, R., Sexton, C., Franklin, T., & Gerlovich, J. (2005). *Teaching science for all children: An inquiry approach* (4th ed.). Boston: Pearson Allyn and Bacon.

Matthews, M.R. (2002) Constructivism and science education: A further appraisal. *Journal of Science Education and Technology*, Vol. 11, 121-134

McComas, W.F. (1998). The principal elements of the nature of science: Dispelling the myths. In W.F. McComas (Ed.), *The nature of science in science education: Rationales and strategies* (pp. 53-70). Dordrecht, NL: Kluwer Academic Publishers.

Morrison, J.A. & Lederman, N.G. (2003). Science teachers' diagnosis and understanding of students' preconceptions. *Science Education, 67*, 849–867.

Musheno, B.V., & Lawson, A.E. (1999). Effects of learning cycle and traditional text on comprehension of science concepts by students at different reasoning levels. *Journal of Research in Science Teaching, 36*, 23-37.

National Research Council [NRC]. (1996). *National Science Education Standards*. Washington, DC: National Academy Press.

Norman, O. (1997). Investigating the nature of formal reasoning in chemistry: Testing Lawson's multiple hypothesis theory. *Journal of Research in Science Teaching, 34,* 1067-1081.

Oakley, B., Weinstein, J. (Writers), & Archer, W. (Director). (1995). Bart vs. Australia [Television series episode]. In M. Groening (Producer), *The Simpsons*. Los Angeles: Twentieth Century Fox Film Corporation.

Operation Physics (1998). *Operation physics: Children's science misconceptions*. Retrieved August 5, 2005 from http://www.amasci.com/miscon/opphys.html

Palmer, D.A. (2003). Investigating the relationship between refutational text and conceptual change. *Science Education, 87*, 663-684.

Piaget, J. (1954). *The construction of reality in the child.* New York: Basic Books.

Posner, G.J., Strike, K.A., Hewson, P.W., & Gertzog, W.A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*, 211-227.

Renner, J.W. (1982). The power of purpose. *Science Education, 66*, 709-716.

Renner, J.W., Abraham, M.R., & Birnie, H.H. (1988). The necessity of each phase of the learning cycle in teaching high school physics. *Journal of Research in Science Teaching, 25*, 39-58.

Schoon, K.J. & Boone, W.J. (1998). Self efficacy and alternative conceptions of science of preservice elementary teachers. *Science Education, 82,* 553-568.

Schneps, M.H. (Producer). (1997). *Minds of Our Own* [Motion picture]. (Available from the Harvard-Smithsonian Center for Astrophysics. Cambridge, MA)

Settlage, J. (2000). Understanding the learning cycle: Influences on abilities to embrace the approach by preservice elementary school teachers. *Science Education, 84*, 43-50.

Simon Fraser University (2005). *Calendar course description: Designs for learning: Elementary science.* Retrieved February 8, 2006 from http://www3.reg.sfu.ca/Tango/course_index/search.taf?function=detail&Layout_0_uid1=34110%2E000000

Simpson, W.D., & Marek, E.A. (1988). Understandings and misconception of biology concepts held by students attending small high schools and students attending large high schools. *Journal of Research in Science Teaching, 25*, 361-374.

Songer, N.B., Lee, H-S., & McDonald, S. (2002) Research toward an expanded understanding of inquiry science beyond one idealized standard. *Science Education,* 87, 490-516.

Staver, J.R. (1998). Constructivism: Sound theory for explicating the practice of science and science teaching. *Journal of Research in Science Teaching, 35*, 501-520.

Stepans, J. (2003). *Targeting students' science misconceptions: Physical science concepts using the conceptual change model.* Tampa, FL: Showboard, Inc.

Sterling, H.A. (1999). Teaching with Dewey on my shoulder: John Dewey's ideas about interaction and continuity contribute to the teaching and learning of science. *Science and Children, 37*, 22-25.

Sweetland, R. (2005). *Misconception directory.* Retrieved August 5, 2005 from http://www.huntel.net/rsweetland/science/misconceptions/

Thomas, M. (2004) Was Einstein learning disabled?: Anatomy of a myth. *Skeptic, 10,* 40-47.

Tobin, K., & Gallagher, J.J. (1987). The role of target students in the science classroom. *Journal of Research in Science Teaching, 24*, 61-75.

Tobin, K., Tippins, D.J. & Gallard, A.J. (1994) Research on instructional strategies for teaching science. In D.L. Gabel (Ed.), *Handbook of research in science teaching and learning.* New York: Macmillan.

University of British Columbia (2005). *CUST – Science education – Course descriptions.* Retrieved February 8, 2006 from http://www.cust.educ.ubc.ca/programs_/sced/coursedescriptions.html

Vygotsky, L.S. (1978). *Mind in Society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Wallace, J., & Louden, W. (1992). Science teaching and teachers' knowledge: Prospects for reform of elementary classrooms. *Science Education, 76,* 507-521.

Wandersee, J.H. (1986). Can the history of science help science educators anticipate students' misconceptions? *Journal of Research in Science Teaching, 23,* 581-597.

Wandersee, J.H., Mintzes, J.J., & Novak, J.D. (1994). Research on alternative conceptions in science. In D.L. Gabel (Ed.), *Handbook of research on science teaching and learning.* New York: Macmillan.

Ward, C.R., & Herron, J.D. (1980). Helping students understand formal chemical concepts. *Journal of Research in Science Teaching, 17,* 387-400.

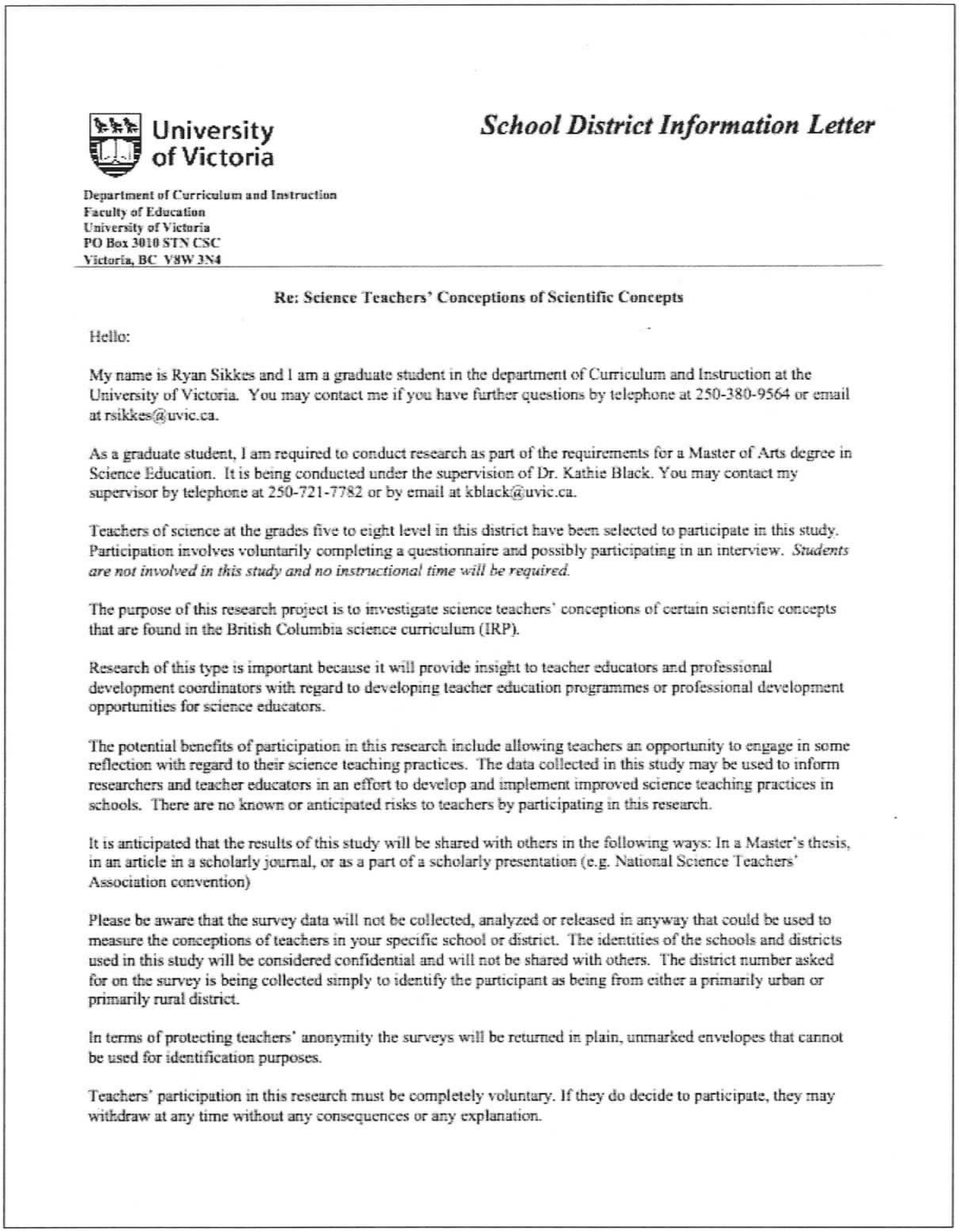
Weber, S. (1999). *Using the science misconceptions research to address science teaching misconceptions.* Oswego, NY: State University of New York. (ERIC Document Reproduction Service No. ED442661).

Windschitl, M. (1999) The challenges of sustaining a constructivist classroom culture. *Phi Delta Kappan, 80,* 751-755.

Yore, L.D. (2001). What is meant by constructivist science teaching and will the science education community stay the course for meaningful reform? *Electronic Journal of Science Education, 5*, 1-5.

Yore, L.D., Hand, B.M., & Florence, M.K. (2004). Scientists' views of science, models of writing, and science writing practices. *Journal of Research in Science Teaching, 41*, 338-369.

APPENDIX A – Letters of Introduction and Consent Forms



University of Victoria

Department of Curriculum and Instruction
Faculty of Education
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PO Box 3010 STN CSC
Victoria, BC V8W 3N4

School District Information Letter

Re: Science Teachers' Conceptions of Scientific Concepts

Hello:

My name is Ryan Sikkes and I am a graduate student in the department of Curriculum and Instruction at the University of Victoria. You may contact me if you have further questions by telephone at 250-380-9564 or email at rsikkes@uvic.ca.

As a graduate student, I am required to conduct research as part of the requirements for a Master of Arts degree in Science Education. It is being conducted under the supervision of Dr. Kathie Black. You may contact my supervisor by telephone at 250-721-7782 or by email at kblack@uvic.ca.

Teachers of science at the grades five to eight level in this district have been selected to participate in this study. Participation involves voluntarily completing a questionnaire and possibly participating in an interview. *Students are not involved in this study and no instructional time will be required.*

The purpose of this research project is to investigate science teachers' conceptions of certain scientific concepts that are found in the British Columbia science curriculum (IRP).

Research of this type is important because it will provide insight to teacher educators and professional development coordinators with regard to developing teacher education programmes or professional development opportunities for science educators.

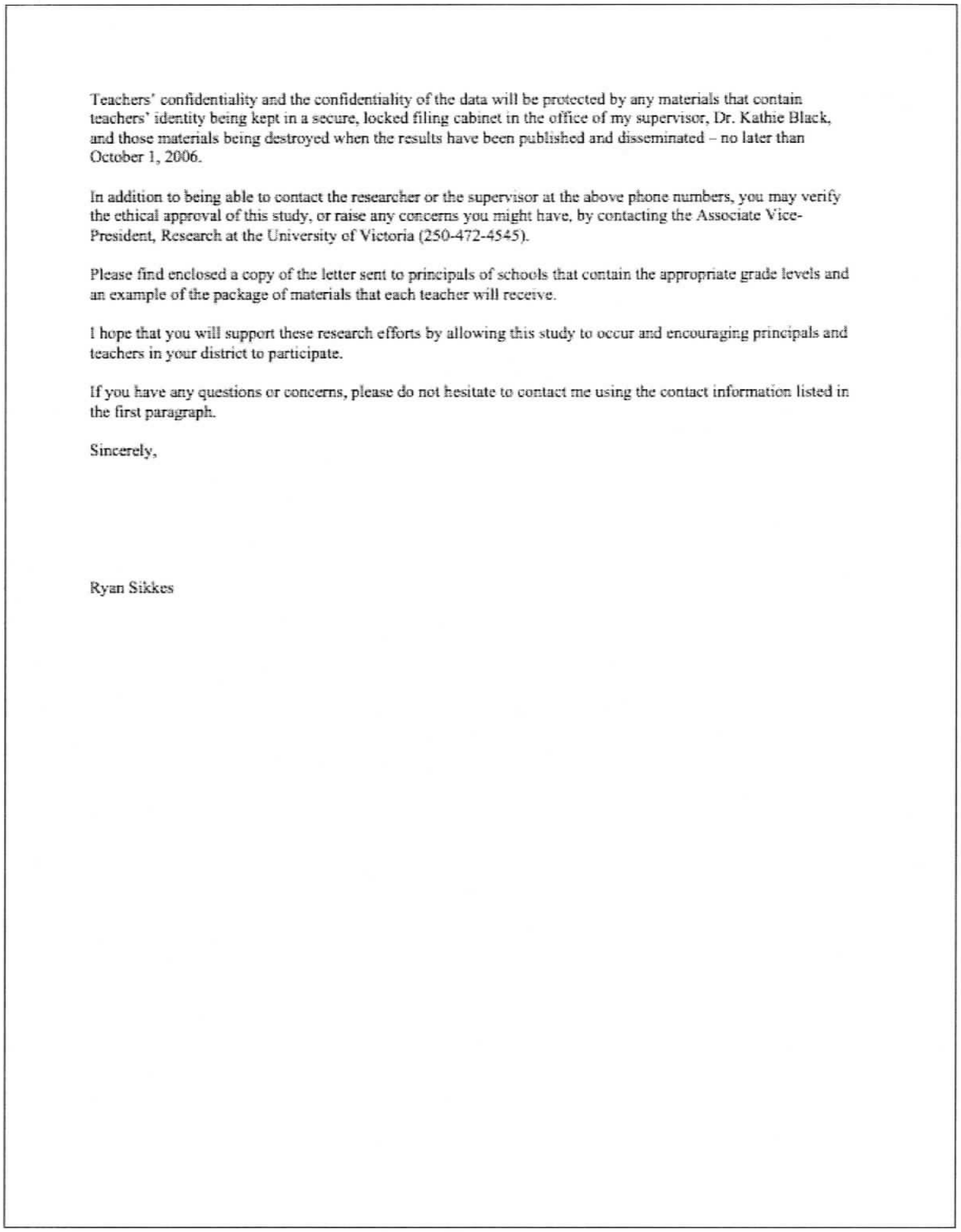
The potential benefits of participation in this research include allowing teachers an opportunity to engage in some reflection with regard to their science teaching practices. The data collected in this study may be used to inform researchers and teacher educators in an effort to develop and implement improved science teaching practices in schools. There are no known or anticipated risks to teachers by participating in this research.

It is anticipated that the results of this study will be shared with others in the following ways: In a Master's thesis, in an article in a scholarly journal, or as a part of a scholarly presentation (e.g. National Science Teachers' Association convention)

Please be aware that the survey data will not be collected, analyzed or released in anyway that could be used to measure the conceptions of teachers in your specific school or district. The identities of the schools and districts used in this study will be considered confidential and will not be shared with others. The district number asked for on the survey is being collected simply to identify the participant as being from either a primarily urban or primarily rural district.

In terms of protecting teachers' anonymity the surveys will be returned in plain, unmarked envelopes that cannot be used for identification purposes.

Teachers' participation in this research must be completely voluntary. If they do decide to participate, they may withdraw at any time without any consequences or any explanation.



Teachers' confidentiality and the confidentiality of the data will be protected by any materials that contain teachers' identity being kept in a secure, locked filing cabinet in the office of my supervisor, Dr. Kathie Black, and those materials being destroyed when the results have been published and disseminated – no later than October 1, 2006.

In addition to being able to contact the researcher or the supervisor at the above phone numbers, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Associate Vice-President, Research at the University of Victoria (250-472-4545).

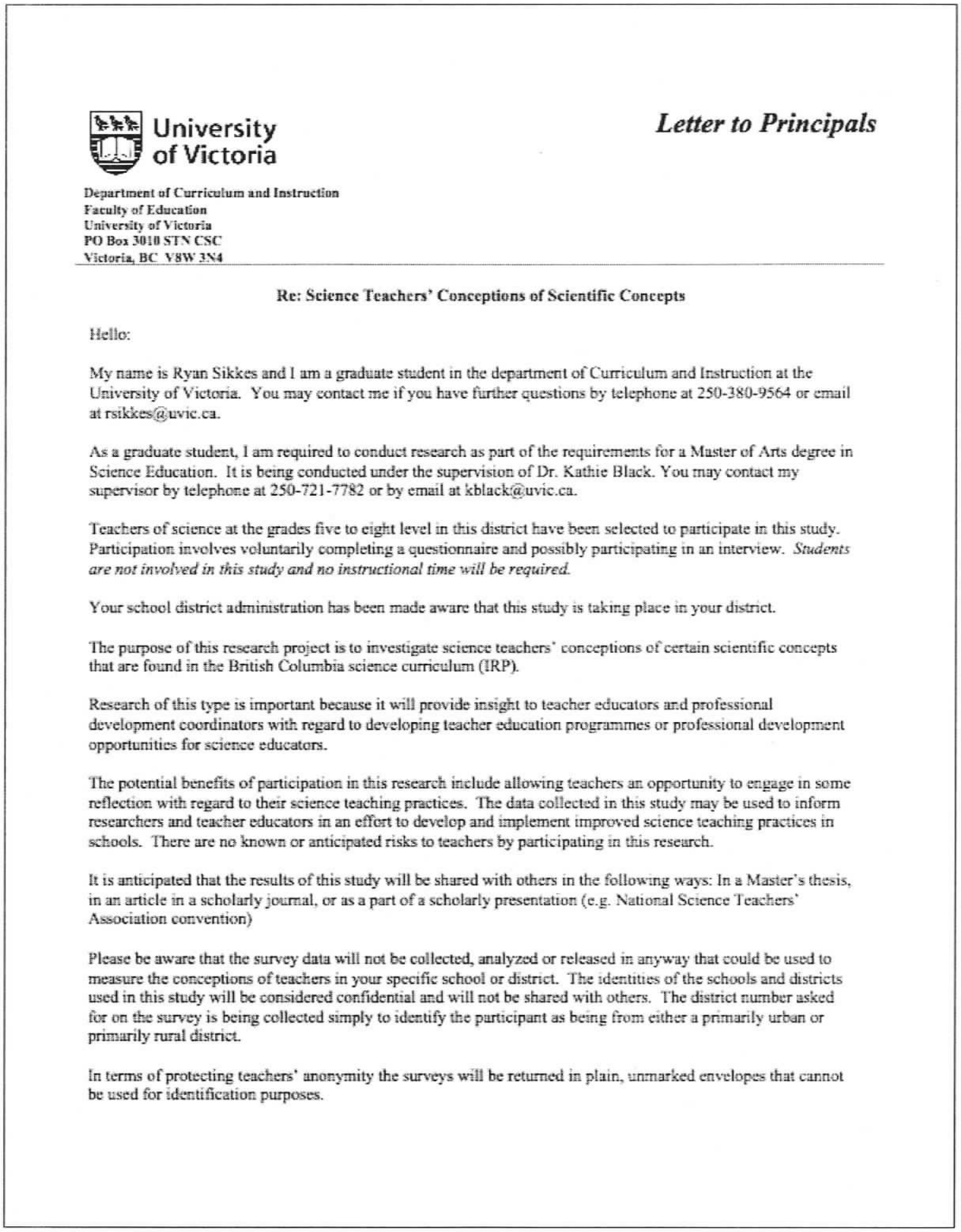
Please find enclosed a copy of the letter sent to principals of schools that contain the appropriate grade levels and an example of the package of materials that each teacher will receive.

I hope that you will support these research efforts by allowing this study to occur and encouraging principals and teachers in your district to participate.

If you have any questions or concerns, please do not hesitate to contact me using the contact information listed in the first paragraph.

Sincerely,

Ryan Sikkes



University
of Victoria

Department of Curriculum and Instruction
Faculty of Education
University of Victoria
PO Box 3010 STN CSC
Victoria, BC V8W 3N4

Letter to Principals

Re: Science Teachers' Conceptions of Scientific Concepts

Hello:

My name is Ryan Sikkes and I am a graduate student in the department of Curriculum and Instruction at the University of Victoria. You may contact me if you have further questions by telephone at 250-380-9564 or email at rsikkes@uvic.ca.

As a graduate student, I am required to conduct research as part of the requirements for a Master of Arts degree in Science Education. It is being conducted under the supervision of Dr. Kathie Black. You may contact my supervisor by telephone at 250-721-7782 or by email at kblack@uvic.ca.

Teachers of science at the grades five to eight level in this district have been selected to participate in this study. Participation involves voluntarily completing a questionnaire and possibly participating in an interview. *Students are not involved in this study and no instructional time will be required.*

Your school district administration has been made aware that this study is taking place in your district.

The purpose of this research project is to investigate science teachers' conceptions of certain scientific concepts that are found in the British Columbia science curriculum (IRP).

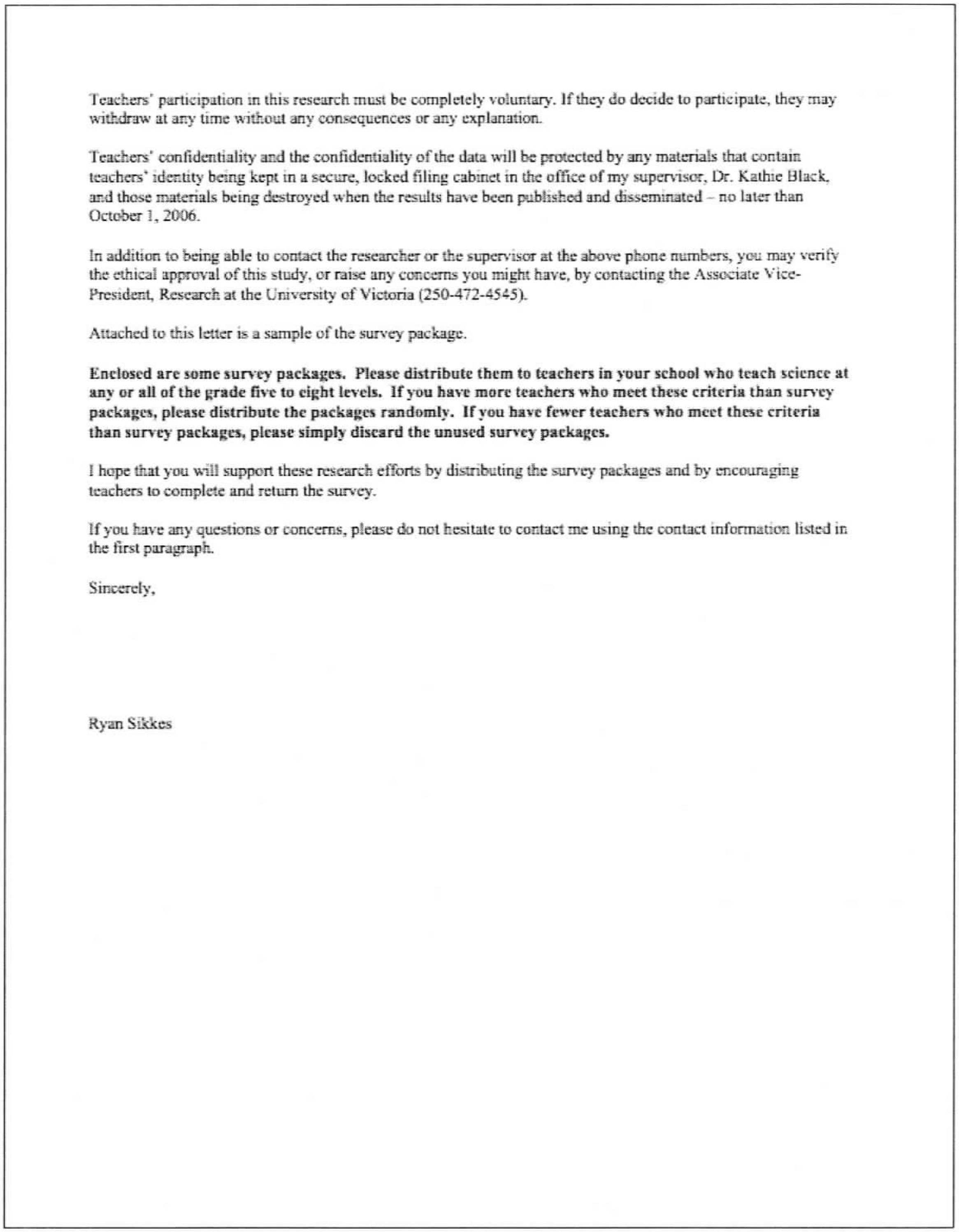
Research of this type is important because it will provide insight to teacher educators and professional development coordinators with regard to developing teacher education programmes or professional development opportunities for science educators.

The potential benefits of participation in this research include allowing teachers an opportunity to engage in some reflection with regard to their science teaching practices. The data collected in this study may be used to inform researchers and teacher educators in an effort to develop and implement improved science teaching practices in schools. There are no known or anticipated risks to teachers by participating in this research.

It is anticipated that the results of this study will be shared with others in the following ways: In a Master's thesis, in an article in a scholarly journal, or as a part of a scholarly presentation (e.g. National Science Teachers' Association convention)

Please be aware that the survey data will not be collected, analyzed or released in anyway that could be used to measure the conceptions of teachers in your specific school or district. The identities of the schools and districts used in this study will be considered confidential and will not be shared with others. The district number asked for on the survey is being collected simply to identify the participant as being from either a primarily urban or primarily rural district.

In terms of protecting teachers' anonymity the surveys will be returned in plain, unmarked envelopes that cannot be used for identification purposes.



Teachers' participation in this research must be completely voluntary. If they do decide to participate, they may withdraw at any time without any consequences or any explanation.

Teachers' confidentiality and the confidentiality of the data will be protected by any materials that contain teachers' identity being kept in a secure, locked filing cabinet in the office of my supervisor, Dr. Kathie Black, and those materials being destroyed when the results have been published and disseminated – no later than October 1, 2006.

In addition to being able to contact the researcher or the supervisor at the above phone numbers, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Associate Vice-President, Research at the University of Victoria (250-472-4545).

Attached to this letter is a sample of the survey package.

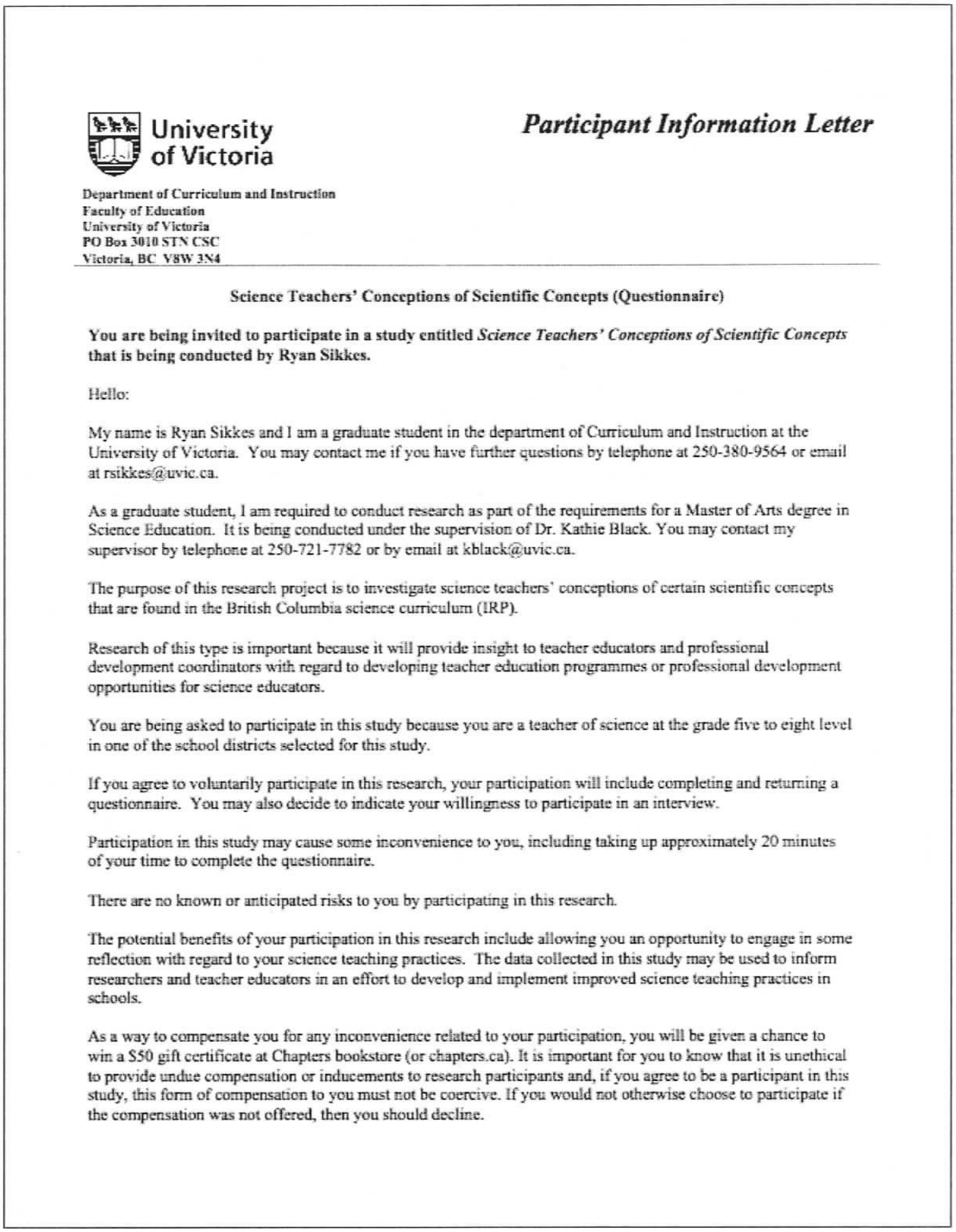
Enclosed are some survey packages. Please distribute them to teachers in your school who teach science at any or all of the grade five to eight levels. If you have more teachers who meet these criteria than survey packages, please distribute the packages randomly. If you have fewer teachers who meet these criteria than survey packages, please simply discard the unused survey packages.

I hope that you will support these research efforts by distributing the survey packages and by encouraging teachers to complete and return the survey.

If you have any questions or concerns, please do not hesitate to contact me using the contact information listed in the first paragraph.

Sincerely,

Ryan Sikkes



University of Victoria

Department of Curriculum and Instruction
Faculty of Education
University of Victoria
PO Box 3010 STN CSC
Victoria, BC V8W 3N4

Participant Information Letter

Science Teachers' Conceptions of Scientific Concepts (Questionnaire)

You are being invited to participate in a study entitled *Science Teachers' Conceptions of Scientific Concepts* that is being conducted by Ryan Sikkes.

Hello:

My name is Ryan Sikkes and I am a graduate student in the department of Curriculum and Instruction at the University of Victoria. You may contact me if you have further questions by telephone at 250-380-9564 or email at rsikkes@uvic.ca.

As a graduate student, I am required to conduct research as part of the requirements for a Master of Arts degree in Science Education. It is being conducted under the supervision of Dr. Kathie Black. You may contact my supervisor by telephone at 250-721-7782 or by email at kblack@uvic.ca.

The purpose of this research project is to investigate science teachers' conceptions of certain scientific concepts that are found in the British Columbia science curriculum (IRP).

Research of this type is important because it will provide insight to teacher educators and professional development coordinators with regard to developing teacher education programmes or professional development opportunities for science educators.

You are being asked to participate in this study because you are a teacher of science at the grade five to eight level in one of the school districts selected for this study.

If you agree to voluntarily participate in this research, your participation will include completing and returning a questionnaire. You may also decide to indicate your willingness to participate in an interview.

Participation in this study may cause some inconvenience to you, including taking up approximately 20 minutes of your time to complete the questionnaire.

There are no known or anticipated risks to you by participating in this research.

The potential benefits of your participation in this research include allowing you an opportunity to engage in some reflection with regard to your science teaching practices. The data collected in this study may be used to inform researchers and teacher educators in an effort to develop and implement improved science teaching practices in schools.

As a way to compensate you for any inconvenience related to your participation, you will be given a chance to win a $50 gift certificate at Chapters bookstore (or chapters.ca). It is important for you to know that it is unethical to provide undue compensation or inducements to research participants and, if you agree to be a participant in this study, this form of compensation to you must not be coercive. If you would not otherwise choose to participate if the compensation was not offered, then you should decline.

Your participation in this research must be completely voluntary. If you do decide to participate, you may withdraw at any time without any consequences or any explanation. If you do withdraw from the study after you mail in your questionnaire, your data cannot be removed from the data set. If you would like to withdraw from the study, please contact Dr. Kathie Black at 250-721-7782 or by email kblack@uvic.ca; or contact the Curriculum and Instruction graduate secretary at 250-721-7882 or by email at ktecampe@uvic.ca

In terms of protecting your anonymity the surveys will be returned in plain, unmarked envelopes that cannot be used to identify you.

Your confidentiality and the confidentiality of the data will be protected by any materials that contain your identity being kept in a secure, locked filing cabinet in the office of my supervisor, Dr. Kathie Black, and those materials being destroyed when the results have been published and disseminated – no later than October 1, 2006.

It is anticipated that the results of this study will be shared with others in the following ways: In a Master's thesis, in an article in a scholarly journal, or as a part of a scholarly presentation (e.g. National Science Teachers' Association convention)

Data from this study will be disposed of upon the completion of the thesis. All original questionnaires will be shredded.

Individuals that may be contacted regarding this study include those listed at the beginning of this letter.

In addition to being able to contact the researcher or the supervisor at the above phone numbers, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Associate Vice-President, Research at the University of Victoria (250-472-4545).

Your consent to the above will be implied if you send back the enclosed questionnaire.

University
of Victoria

Department of Curriculum and Instruction
Faculty of Education
University of Victoria
PO Box 3010 STN CSC
Victoria, BC V8W 3N4

Compensation, Interview and Return Information

Thank you for agreeing to participate in this study.

1. Compensation

To be eligible to win the $50 gift certificate from Chapters (or chapters.ca), you must return this form with your contact information on it.

Name: ______________________________

Mailing address: ______________________________

Phone number: (work) ______________ (home) ______________

Email address: ______________________________

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2. Interview

A second portion of this study involves interviewing selected participants in order to obtain more in-depth answers to some of the questions raised by the data contained in the questionnaires.

Interviews would be conducted in early December and would last no longer than one hour and would be conducted either in person (if circumstances allow) or by telephone.

Please initial here: _______ if you would be interested in participating in an interview.

If you are selected to participate, you will be contacted by telephone at the number(s) you supplied above. You will also be supplied with another consent form.

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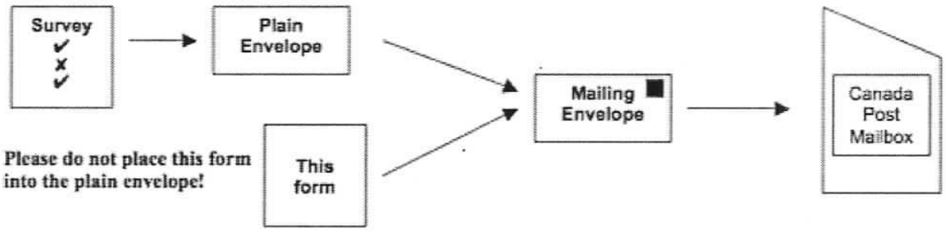
3. Return Information • All questionnaires must be mailed by November 15, 2005.



Please do not place this form into the plain envelope!

Please note: This form will also be destroyed at the conclusion of the study.

University
of Victoria

Department of Curriculum and Instruction
Faculty of Education
University of Victoria
PO Box 3010 STN CSC
Victoria, BC V8W 3N4

Participant Consent Form
INTERVIEW

Science Teachers' Conceptions of Scientific Concepts (Interview)

Thank you for volunteering to continue to participate in a study entitled *Science Teachers' Conceptions of Scientific Concepts* that is being conducted by Ryan Sikkes.

Ryan Sikkes is a graduate student in the department of Curriculum and Instruction at the University of Victoria and you may contact him if you have further questions by telephone at 250-380-9564 or email at rsikkes@uvic.ca.

As a graduate student, I am required to conduct research as part of the requirements for a Master of Arts degree in Science Education. It is being conducted under the supervision of Dr. Kathie Black. You may contact my supervisor by telephone at 250-721-7782 or by email at kblack@uvic.ca.

The purpose of this research project is to investigate science teachers' conceptions of certain scientific concepts that are found in the British Columbia science curriculum (IRP).

Research of this type is important because it will provide insight to teacher educators and professional development coordinators with regard to developing teacher education programmes or professional development opportunities for science educators.

You are being asked to participate in this study because you indicated your willingness to participate when you completed the questionnaire I mailed to you a short time ago.

If you agree to voluntarily participate in this aspect of the research, your participation will include engaging in a personal or telephone interview.

Participation in this study may cause some inconvenience to you, including taking up approximately one hour of your time to complete the interview.

There are no known or anticipated risks to you by participating in this research.

The potential benefits of your participation in this research include allowing you an opportunity to engage in some reflection with regard to your science teaching practices. The data collected in this study may be used to inform researchers and teacher educators in an effort to develop and implement improved science teaching practices in schools.

Your participation in this research must be completely voluntary. If you do decide to participate, you may withdraw at any time without any consequences or any explanation. If you do withdraw from the study, your data will not be used. If you would like to withdraw from the study, please contact Dr. Kathie Black at 250-721-7782 or by email kblack@uvic.ca; or contact the Curriculum and Instruction graduate secretary at 250-721-7882 or by email at ktecampe@uvic.ca

In terms of protecting your anonymity, you will be assigned a pseudonym and no details that would allow someone to identify you will be revealed in any published materials or in presentations.

Your confidentiality and the confidentiality of the data will be protected by any materials that contain your identity being kept in a secure, locked filing cabinet in the office of my supervisor, Dr. Kathie Black, and those materials being destroyed when the results have been published and disseminated – no later than October 1, 2006.

It is anticipated that the results of this study will be shared with others in the following ways: In a Master's thesis, in an article in a scholarly journal, or as a part of a scholarly presentation (e.g. National Science Teachers' Association convention)

Data from this study will be disposed of upon the completion of the thesis. All recordings of the interviews will be destroyed by magnetically erasing all cassette tapes used and shredding all written notes.

Individuals that may be contacted regarding this study include those listed at the beginning of this letter.

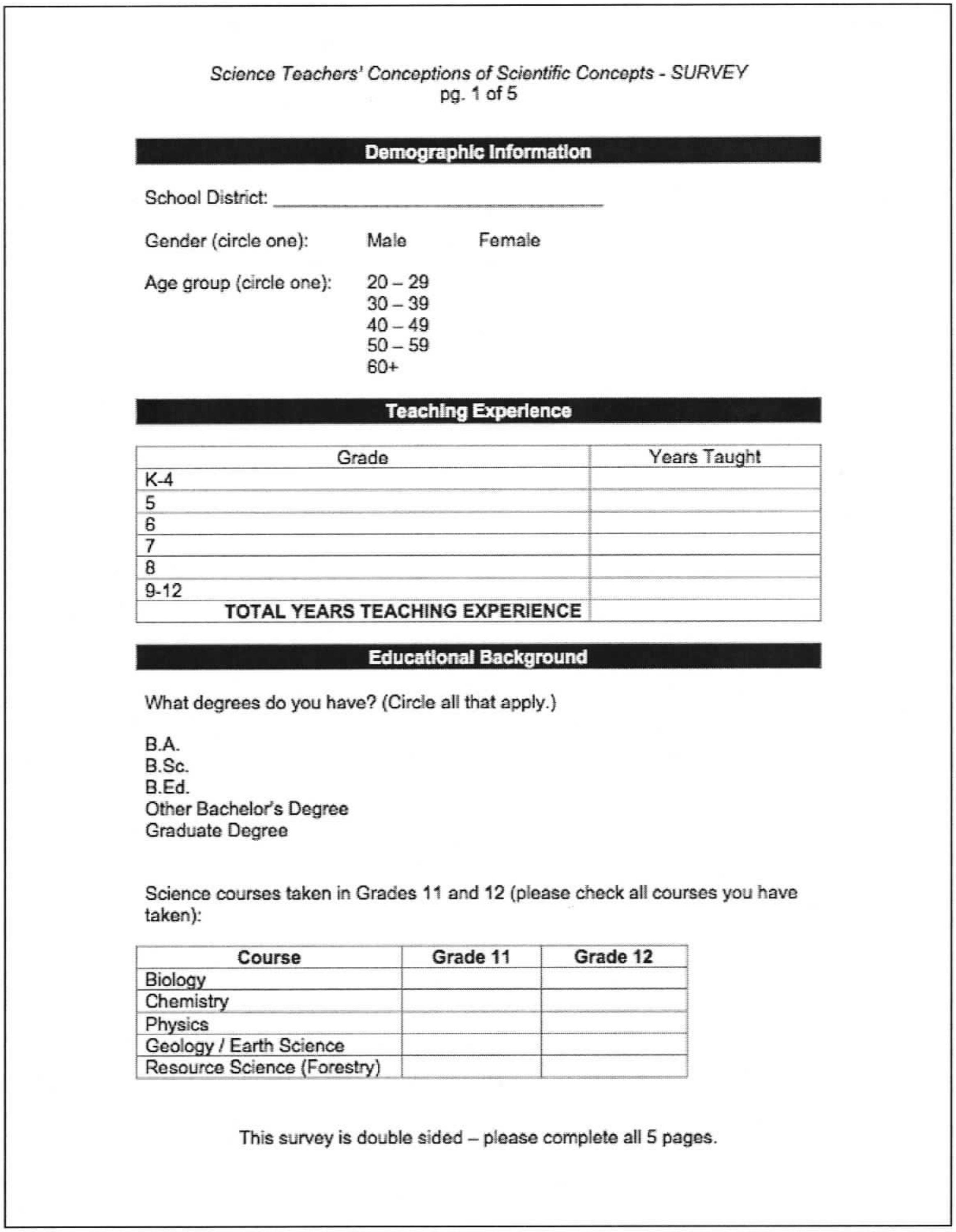
In addition to being able to contact the researcher or the supervisor at the above phone numbers, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Associate Vice-President, Research at the University of Victoria (250-472-4545).

Your signature below indicates that you understand the above conditions of participation in this study and that you have had the opportunity to have your questions answered by the researchers.

Name of Participant	*Signature*	*Date*

Please keep one copy of this letter and return the other in the enclosed mailing envelope.

APPENDIX B - Questionnaire



Science Teachers' Conceptions of Scientific Concepts - SURVEY
pg. 1 of 5

Demographic Information

School District: ______________________________

Gender (circle one): Male Female

Age group (circle one):
20 – 29
30 – 39
40 – 49
50 – 59
60+

Teaching Experience

Grade	Years Taught
K-4	
5	
6	
7	
8	
9-12	
TOTAL YEARS TEACHING EXPERIENCE	

Educational Background

What degrees do you have? (Circle all that apply.)

B.A.
B.Sc.
B.Ed.
Other Bachelor's Degree
Graduate Degree

Science courses taken in Grades 11 and 12 (please check all courses you have taken):

Course	**Grade 11**	**Grade 12**
Biology		
Chemistry		
Physics		
Geology / Earth Science		
Resource Science (Forestry)		

This survey is double sided – please complete all 5 pages.

Science Teachers' Conceptions of Scientific Concepts - SURVEY
pg. 2 of 5

Please indicate (by circling) the **number of science content courses** (not methods/pedagogy courses) taken at the university level.

Biology	0	1	2	3	4	5+
Chemistry	0	1	2	3	4	5+
Physics	0	1	2	3	4	5+
Geology/Earth Science	0	1	2	3	4	5+
Environmental Science	0	1	2	3	4	5+

Self-assessment of content knowledge

For the grade level(s) that I teach, I would consider my science content knowledge to be:

1	2	3	4	5	6	7	8	9
low				adequate				high

High school science classes provide enough content knowledge to teach elementary/middle school.

1	2	3	4
Disagree strongly	Disagree	Agree	Agree Strongly

Prospective elementary/middle school teachers should be required to take more science **content** (not methods/pedagogy) courses.

1	2	3	4
Disagree strongly	Disagree	Agree	Agree Strongly

Prospective elementary/middle school teachers should be required to take more science **methods**/pedagogy courses.

1	2	3	4
Disagree strongly	Disagree	Agree	Agree Strongly

This survey is double sided – please complete all 5 pages.

Science Teachers' Conceptions of Scientific Concepts - SURVEY
pg. 3 of 5

Classroom Practices

For each of the following classroom practices, please indicate (by checking the appropriate box) how often your students experience them when learning **science:**

	Every Class	Frequently, but not always	Occasionally	Never
Work in groups				
Open-ended activities / labs				
Hands-on activities with specific instructions				
Listening and taking notes from the teacher				
Answer textbook or worksheet questions				
Record, represent, and/or analysis data				
Read from a science textbook in class				
Write reflections				
Watch a science demonstration				
Prepare written science reports				
Watch audiovisual presentations				
Design or implement their own investigation				
Work on extended science investigations or projects				
Use computers as a tool				
Make formal presentations to the class				
Take field trips				

This survey is double sided – please complete all 5 pages.

Science Teachers' Conceptions of Scientific Concepts - SURVEY
pg. 4 of 5

Ideas about science

The following is a list of ideas about science that are either true or false.

Please indicate (by circling) whether you think the following statements are true or false.

Please do not use any references or resources (eg. people or books, etc.) when completing this portion of the questionnaire.

1	"No pain, no gain" is a good rule-of-thumb when exercising.	T	F
2	A ball that is thrown sideways off the top of a building and one that is dropped from the same height will hit the ground at the same time.	T	F
3	A person can be harmed by ingesting too much of a vitamin or mineral.	T	F
4	A person will get cancer if they smoke.	T	F
5	Air and oxygen are the same thing.	T	F
6	All scientists must use the "scientific method" to get proper results.	T	F
7	As plants grow, they gain most of their mass by absorbing nutrients from the soil.	T	F
8	Astronauts have no mass in outer space – that is why they float.	T	F
9	Chemical changes are irreversible.	T	F
10	Christopher Columbus proved that the earth was round.	T	F
11	Continents are constantly moving.	T	F
12	Einstein was a poor student in school because he had learning disabilities.	T	F
13	Electrons surround the nuclei of atoms in well-defined orbits.	T	F
14	Eventually, scientists will find an antibiotic that will cure the common cold.	T	F
15	Gases have weight.	T	F

This survey is double sided – please complete all 5 pages.

Science Teachers' Conceptions of Scientific Concepts - SURVEY
pg. 5 of 5

16	Heat from the oven or stove is required to initiate a chemical reaction when cooking.	T	F
17	Heavy objects fall faster than lighter objects.	T	F
18	Humans and dinosaurs lived on the earth at the same time.	T	F
19	Hypotheses develop into theories and, finally, into laws.	T	F
20	If a crystal can scratch glass, it must be a diamond.	T	F
21	If you exercise regularly, you can eat whatever you want and not worry about gaining weight.	T	F
22	It is possible for iron to freeze.	T	F
23	Melting ice is a physical change because no new substances are produced.	T	F
24	Mountains are rapidly created.	T	F
25	Newton discovered gravity when an apple dropped on his head.	T	F
26	Placing one's hand in a bucket of cold water feels cold because the cold is moving from the water to the hand.	T	F
27	The earth revolves around the sun once per year.	T	F
28	The knowledge base in biology, chemistry and physics is interrelated.	T	F
29	The phases of the moon are caused by the shadow of the earth being cast on the moon.	T	F
30	The proximity of the earth to the sun causes the seasons.	T	F
31	The size of a magnet determines its strength	T	F
32	The speed of a pendulum will change if the weight of the bob is increased or decreased.	T	F
33	The water drains in the opposite direction down the drain in the southern hemisphere.	T	F
34	When liquid water is boiled into steam, it occupies more space because the particles become larger.	T	F

This survey is double sided – please complete all 5 pages.

APPENDIX C – Interview Protocol

Science Teachers' Conceptions of Scientific Concepts

Interview Protocol

Inform person that the conversation is being recorded.

Review the consent forms and ask if any questions.

Confirm demographic information from reply email.

Training:

The questionnaire contained four opinion questions. I will read you each one and I would like you to tell me, to the best of your memory, how you responded. As well, I'd like to know the reasons why you picked each particular level and not another.

For the grade level(s) that I teach, I would consider my science content knowledge to be: (what did you use as the criteria for this – the requirements for licensure, the curriculum, your personal comfort with the topics)?

1	2	3	4	5	6	7	8	9
low				adequate				high

High school science classes provide enough content knowledge to teach elementary/middle school.

1	2	3	4
Disagree strongly	Disagree	Agree	Agree Strongly

Many teachers responded that they felt that high school science courses were adequate preparation to teach science at the gr. 5-8 level. How does your experiences with high school science influence your teaching?

Prospective elementary/middle school teachers should be required to take more science **content** (not methods/pedagogy) courses.

1	2	3	4
Disagree strongly	Disagree	Agree	Agree Strongly

Did your university training provide adequate content knowledge for teaching science in grades 5 through 8? Describe your university training in terms of science content.

Prospective elementary/middle school teachers should be required to take more science **methods**/pedagogy courses.

1	2	3	4
Disagree strongly	Disagree	Agree	Agree Strongly

Most respondents said that prospective teachers should take more science content and more science methods courses in their university training. Why do you think this is so?

What types of things did you learn about misconceptions of the role of prior knowledge in your science methods course that you took as part of your education program?

How could your university training could have been improved in terms of preparation to teach science?

Constructivism/Inquiry:

Please tell me what you know about constructivism.

Do you agree with this theory of learning? Why or why not?

Please tell me what you know about inquiry as a method of instruction. (If necessary, explain it).

What role does a student's prior knowledge about a topic play in them being able to learn new knowledge?

Can students' misconceptions about various topics be helpful when teaching science?

Where do students obtain misconceptions about science?

Classroom Practices:

What are classroom practices you use most when teaching science?

What types of things do you do everyday?

What types of things did you wish you could do more of?

How do you ascertain students' prior knowledge about a topic?

86% of teachers report occasional or frequent use of the practice of teachers allowing students to design and implement their own investigations. Do you do this and how does it look in your classroom?

In general, most teachers in this study reported more frequent use of 'traditional' teaching practices such as reading from the text book in class, answering textbook and worksheet questions, and listening to the teacher and taking notes rather than inquiry practices like designing experiments and collecting and interpreting data. What are some of the barriers, in your opinion, as to why teachers might avoid using inquiry methods?

Specific Misconceptions:

Do you recall whether or not you have ever taught something that you later found out was incorrect?

For specific misconceptions, get answer and then why they think that and where they obtained that knowledge?

Example: Water down the drain opposite direction in southern hemisphere? Why do you think it does/does not? Do you remember where or how you learned that?

What are some common misconceptions that you have experience students having? How do you address these?

Professional Development:

Do you have access to professional development opportunities in terms of science education?

What type of professional development opportunities would you like to see offered to help you and your colleagues become better science teachers?

Would you agree collaboration between high school teachers and elementary teachers would be beneficial?

APPENDIX D – Completed Tables

Table D.1: Respondents' School Districts

School District	**Frequency**	**Valid Percentage**
None given	40	44.4 %
22	2	2.2 %
27	1	1.1 %
33	3	3.3 %
35	5	5.6 %
36	5	5.6 %
37	3	3.3 %
38	3	3.3 %
39	4	4.4 %
45	1	1.1 %
54	3	3.3 %
57	3	3.3 %
60	2	2.2 %
61	5	5.6 %
63	1	1.1 %
65	1	1.1 %
68	2	2.2 %
73	3	3.3 %
82	3	3.3 %

Table D.2 (Complete version of *Table 4.5*): Classroom practices employed by science teachers

	Every Class (4)	Frequently, but not always (3)	Occasionally (2)	Never (1)	Mean
Listening and taking notes from the teacher	10	48	29	3	2.72
Work in groups	2	60	28	0	2.71
Hands-on activities with specific instructions	5	51	31	0	2.70
Answer textbook or worksheet questions	5	43	38	3	2.56
Record, represent, and/or analyze data	4	39	45	1	2.52
Open-ended activities / labs	3	31	51	1	2.42
Watch a science demonstration	1	34	54	1	2.39
Read from a science textbook in class	6	34	34	15	2.35
Prepare written science reports	0	23	60	5	2.20
Watch audiovisual presentations	0	20	65	4	2.18
Use computers as a tool	0	23	53	13	2.11
Make formal presentations to the class	0	15	68	7	2.09
Take field trips	0	14	70	6	2.09
Write reflections	2	17	51	20	2.01
Design or implement their own investigation	0	12	65	13	1.99
Work on extended science investigations or projects	0	14	57	19	1.94

Table D.3 (Complete version of *Table 4.8*)*:* Correct responses to misconceptions

CO*	Idea	% Correct
NSP	Einstein was a poor student in school because he had learning disabilities. (F)	25.0
ESS	The water drains in the opposite direction down the drain in the southern hemisphere. (F)	31.1
ESS	The phases of the moon are caused by the shadow of the earth being cast on the moon. (F)	33.7
PS	Heat from the oven or stove is required to initiate a chemical reaction when cooking. (F)	38.2
NSP	Hypotheses develop into theories and, finally, into laws. (F)	38.6
PS	Electrons surround the nuclei of atoms in well-defined orbits. (F)	40.2
PS	The speed of a pendulum will change if the weight of the bob is increased or decreased. (F)	46.6
NSP	Newton discovered gravity when an apple dropped on his head. (F)	53.4
LS	As plants grow, they gain most of their mass by absorbing nutrients from the soil. (F)	53.9
NSP	All scientists must use the "scientific method" to get proper results. (F)	56.7
ESS	The proximity of the earth to the sun causes the seasons. (F)	57.3
PS	A ball that is thrown sideways off the top of a building and one that is dropped from the same height will hit the ground at the same time. (T)	61.1
PS	Chemical changes are irreversible. (F)	68.2
PS	Heavy objects fall faster than lighter objects. (F)	71.9
PS	Placing one's hand in a bucket of cold water feels cold because the cold is moving from the water to the hand. (F)	76.1
ESS	If a crystal can scratch glass, it must be a diamond. (F)	76.7
PS	It is possible for iron to freeze. (T)	78.8
NSP	Christopher Columbus proved that the earth was round. (F)	80.5
LS/ NSP	Humans and dinosaurs lived on the earth at the same time. (F)	80.5
PS	The size of a magnet determines its strength. (F)	83.0
PS	When liquid water is boiled into steam, it occupies more space because the particles become larger. (F)	85.4

PS	Astronauts have no mass in outer space – that is why they float. (F)	85.6
LS	Eventually, scientists will find an antibiotic that will cure the common cold. (F)	85.6
LS	"No pain, no gain" is a good rule-of-thumb when exercising. (F)	86.5
ESS	Mountains are rapidly created. (F)	88.6
NSP	The knowledge base in biology, chemistry and physics is interrelated. (T)	91.0
LS	A person can be harmed by ingesting too much of a vitamin or mineral. (T)	91.1
LS/ NSP	A person will get cancer if they smoke. (F)	92.1
PS	Gases have weight. (T)	93.3
PS	Melting ice is a physical change because no new substances are produced. (T)	94.4
ESS	The earth revolves around the sun once per year. (T)	95.5
PS	Air and oxygen are the same thing. (F)	95.6
ESS	Continents are constantly moving. (T)	95.6
LS	If you exercise regularly, you can eat whatever you want and not worry about gaining weight. (F)	98.9

(CO=Curriculum Organizer; LS=Life Sciences; PS=Physical Sciences; ESS=Earth and Space Science; NSP=Nature of Science/Processes)

APPENDIX E – Explanations Of Misconception Statements

CO*	Idea	Answer and Justification
LS	"No pain, no gain" is a good rule-of-thumb when exercising.	False – Muscle pain can simply be caused by lactic acid buildup in the muscles when exercising, but can also be caused by other factors like ligament and tendon damage.
PS	A ball that is thrown sideways off the top of a building and one that is dropped from the same height will hit the ground at the same time.	True – Gravity pulls down objects at the same velocity irregardless of any horizontal motion the object may have.
LS	A person can be harmed by ingesting too much of a vitamin or mineral.	True – Too much of the fat soluble vitamins can cause toxic symptoms (Krebs, 1999) and excess iron and zinc can also cause health problems.
LS/ NSP	A person will get cancer if they smoke.	False – The causation of cancer by smoking has never been proven. However, smoking is very highly correlated with incidents of cancer.
PS	Air and oxygen are the same thing.	False – Air is a mixture of gases including nitrogen, oxygen, carbon dioxide and others. Oxygen is an element, and therefore, is a pure substance.
NSP	All scientists must use the "scientific method" to get proper results.	False – There is no universally accepted 'scientific method' that all scientists follow when performing research (McComas, 1998).
LS	As plants grow, they gain most of their mass by absorbing nutrients from the soil.	False – As plants grow, the process of photosynthesis causes gaseous carbon dioxide to be transformed into cellulose, which makes up most of a plant's weight (Schneps, 1997).
PS	Astronauts have no mass in outer space – that is why they float.	False – Astronauts float because they are in a situation of microgravity, they have not gained or lost matter (and therefore mass)
PS	Chemical changes are irreversible.	False – Chemical changes can be reversed. Dynamic equilibrium is an example of forward and reverse chemical reactions.
NSP	Christopher Columbus proved that the earth was round.	False – Observations of celestial motions and lunar events all provided 'proof' of the earth's roundness long before Columbus sailed to the Americas in 1492.
ESS	Continents are constantly moving.	True – The tectonic plates that make up the earth's crust are always in motion and are the cause of earthquakes.
NSP	Einstein was a poor student in school because he had learning disabilities.	False – Very little evidence exists that suggests that Einstein had any sort of learning disability (Thomas, 2004)

PS	Electrons surround the nuclei of atoms in well-defined orbits.	False – Electrons surround the nuclei of atoms in ill-defined regions of probability known as orbitals (Krebs, 1999).
LS	Eventually, scientists will find an antibiotic that will cure the common cold.	False – The common cold is caused by a virus and cannot be cured by use of an antibiotic, which is only effective against bacterial infections.
PS	Gases have weight.	True – Gases being matter must have mass (and therefore weight).
PS	Heat from the oven or stove is required to initiate a chemical reaction when cooking.	False – Not all chemical reactions involved in cooking are endothermic. An example to the contrary is gelatin setting at room temperature or in the refrigerator.
PS	Heavy objects fall faster than lighter objects.	False – The acceleration due to gravity is the same for all objects.
LS/ NSP	Humans and dinosaurs lived on the earth at the same time.	False – A great deal of fossil evidence proves that dinosaurs became extinct long before the evolution of humans.
NSP	Hypotheses develop into theories and, finally, into laws.	False – Hypotheses that are proven consistently to be true in a number of situations and have predictive power may become theories. Theories remain theories because they cannot be proven to be true in all situations, whereas laws are created when this is the case (McComas, 1998).
ESS	If a crystal can scratch glass, it must be a diamond.	False – Typical glass has a hardness of approximately 5.5 on Moh's Hardness Scale. Minerals such as quartz, topaz, and corundum all are harder than glass and, consequently, will scratch it.
LS	If you exercise regularly, you can eat whatever you want and not worry about gaining weight.	False – If a person ingests more calories than he or she can metabolize, the excess calories are stored in the body as fat.
PS	It is possible for iron to freeze.	True – Freezing is simply the change of state from liquid into solid for any matter. Molten iron freezes as it hardens into solid iron.
PS	Melting ice is a physical change because no new substances are produced.	True – Changes where no new molecules are created are known as physical changes and include all changes of state.
ESS	Mountains are rapidly created.	False – Tectonic plates move very slowly so that even when two plates collide together to form a mountain, the process takes thousands or millions of years.
NSP	Newton discovered gravity when an apple dropped on his head.	False – Although Newton uses the analogy of a falling apple in his works, the anecdote him having a "eureka moment" when an apple fell and hit him on his head is nothing but a story (Fara, 2002).

PS	Placing one's hand in a bucket of cold water feels cold because the cold is moving from the water to the hand.	False – There is no such thing as 'cold' only heat. In this example, the feeling of being cold arises from heat transferring from the hotter object (the hand) to the colder object (the water).
ESS	The earth revolves around the sun once per year.	True – The earth travels in a slightly elliptical path around the sun, making a complete revolution every 365.25 days.
NSP	The knowledge base in biology, chemistry and physics is interrelated.	True – Each discipline of science shares topics with other disciplines. Examples include organic chemistry being studied by chemists and biologists or atomic theory being studied by chemists and physicists.
ESS	The phases of the moon are caused by the shadow of the earth being cast on the moon.	False – The phases of the moon are caused by the position of the moon relative to the earth and the sun. A full moon results when the moon and the sun are on opposite sides of the earth, allowing the light from the sun to reflect off the moon towards the earth. A new moon results then the moon and the sun are on the same side of the earth – no light is reflected off the side of the moon that is facing the earth (Schneps, 1997).
ESS	The proximity of the earth to the sun causes the seasons.	False – The tilt of the earth's axis causes the northern hemisphere to receive more solar energy during the summer months and less in the winter months. The proximity of the earth to the sun is not always constant, but it does not contribute to extra heat in the summer and less in the winter (Baumann, et al., 1995).
PS	The size of a magnet determines its strength.	False – The magnetic force of a huge magnet such as the earth is far smaller than the average refrigerator magnet.
PS	The speed of a pendulum will change if the weight of the bob is increased or decreased.	False – The period of a pendulum is affected by its length, not the mass of the bob. (Posner, et al., 1982).
ESS	The water drains in the opposite direction down the drain in the southern hemisphere.	False – The influence of the Coriolis effect is greatly outweighed by the shape of the vessel, the shape and size of the drain, and the molecular motion of the fluids (Fraser, 1995).
PS	When liquid water is boiled into steam, it occupies more space because the particles become larger.	False – The kinetic molecular theory states that when heat is applied to matter, the particles (atoms or molecules) spread apart – steam occupies more space because the water molecules have more space in between them.

(CO=Curriculum Organizer; LS=Life Sciences; PS=Physical Sciences; ESS=Earth and Space Science; NSP=Nature of Science/Processes)