AN INVESTIGATION INTO THE CONCEPT OF HEAT – A STUDY OF CHEMISTRY INSTRUCTORS' ALTERNATE CONCEPTIONS

by

Donna-Leigh Goodman

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Abstract

Research has shown that chemistry students often possess alternate conceptions regarding the 'heat' concept. This is a problem because understanding heat in chemistry is pivotal to a meaningful comprehension of many other heat-related scientific concepts, such as temperature, kinetic energy, and work. Studies indicate that students frequently exit chemistry courses with inaccurate conceptualizations of heat. The implications for teaching are that whenever students' reasoning about heat is faulty, then it becomes pedagogically important to examine, also, the chemistry instructors' conceptualizations. As language is a powerful method of representation of knowledge and ideas in chemistry education, alternate conceptions may be directly transmitted through inaccurate articulation, such as misused metaphors and analogies.

This investigation involves determining instructors' various understandings of the meaning of the heat concept as taught in college preparation and first-year level chemistry classes. A sample consisting of currently practicing chemistry instructors from local colleges and universities completed a survey-questionnaire describing a lesson on how they teach the heat concept to their students by making an audio digital recording. To support this investigation the chemistry textbooks used by the instructors were linguistically analyzed for definitions and explanations of heat. Analytically, this study employs the qualitative methodology of grounded theory to inductively develop emergent theory from the data through a constant comparative process. Grounded theory allows movement from in-depth studies to more general accounts of wider context which offer testable predictions verifiable by traditional experimental and statistical means.

The results of this study indicate that instructors do hold many alternate conceptions about heat and use them during instruction, of which several or more are discrepant with the accepted views of the scientific community. I argue that chemistry instructors need to identify and understand the use of these alternate conceptions, and find ways to counteract them through conceptual change-based pedagogy, before passing them on to students. I suggest instructors speak about heat as a process rather than as a substance to support development of the correct scientific meaning of heat. This inquiry also shows that chemistry textbooks contain incorrect language, and misconceptions, about the heat concept likely contributing to the problem.

Preface

Ethical approval for this research study was obtained May 25, 2010, from The University of British Columbia, Office of Research Services, Behavioural Research Ethics Board, certificate number H09 – 00143.

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A Glossary of Terms

Absolute Zero - zero kelvin temperature

Actional - systematic information about the way things operate, problem-solving methods, a 'how to' approach

Analogy - similarity, process of reasoning from a parallel case ('is like')

Axiological – the study of the nature of values and value judgments; 'what we take to be of value'

Endothermic Reaction – type of reaction in which more energy is absorbed to break the bonds than is released to form new bonds

Enthalpy – the heat content of a system

Epistemology – theory of the method, grounds of knowledge; 'what we take to be true'

Equilibrium – the condition in any reversible process in which the forward and reverse processes occur at the same rate

Essentialism – objects having an identifying underlying quality or essence

Exothermic Reaction- describing a chemical reaction in which the energy is released to the surroundings

Gibbs' Free Energy – the energy available to do useful work; entropy

Heat of Fusion – the heat required to change one kilogram of matter from a solid to a liquid

Heat of Vaporization – the heat required to change one kilogram of matter from a liquid to a gas

Hess' Law – enthalpy changes for a series of reactions can be added together to describe the energy change for the overall reaction

Ideal Gas Law – a mathematical equation based on the kinetic molecular theory that relates to the amount of gas in a sample to pressure, volume, and temperature

Kelvin Scale – a scale for measuring temperature; based on a zero value equals –273.15 degrees Celsius

Kinetic Energy – energy of motion

Kinetic Molecular Theory (KMT) – a theory that describes the set of conditions for, and behaviour of, ideal gases

Le Chatelier's Principle – a generalization stating that when conditions are changed, a system in equilibrium will adjust to produce a new equilibrium

Metaphor – use of the verb 'is' (*not* 'like'), grammatical processes of identification, grammatically equivalent to statements of category membership, application of name or descriptive term to an object to which it is not literally applicable

Ontology – essence of things, 'what we take to be real'

Ontology and Grammar – every physical model has an underlying ontology of matter, processes, and states, meaning every component of a physical model can be classified into one of these ontological categories, this ontology is encoded in the grammar of each sentence that scientists speak or write

Potential Energy – energy of position or condition; stored energy

Relativism – knowledge is of relations only; the quality of state of being, connected with and interdependent

Rich – the data is full and detailed

Rotational Motion – movement of the molecule around its centre of mass; present in liquids and gases

Semiotics – the study of how we make meaning using the cultural resources of words, images, symbols, and actions

Specific Heat (capacity) – the amount of heat required to raise the temperature of one kilogram of matter one degree Celsius

State-function – a relationship between thermodynamic quantities; a model for a material or system; in thermodynamics, defined by the values of all relevant macroscopic properties, such as composition, energy, temperature, pressure, and volume; these examples are said to be state functions, that is, the properties are determined by the state of the system, regardless of how that condition was achieved; when the state of the system changes, the magnitude of change in any state function depends only on the initial and final states of the system, not on how the change was accomplished

System – the part of the universe that is the focus of a thermodynamic study

Thermodynamics – the branch of chemistry dealing with quantities of heat evolved or absorbed during chemical reactions; the science of the relationship between heat and mechanical work (or other forms of energy); the first law of thermodynamics means that the change in internal energy is equal to the energy input minus the energy output due to or is the law of conservation of energy

> **The First Law of Thermodynamics** – the change in internal energy is equal to the energy input minus the energy output due to the law of conservation of energy

Translational Motion – the movement of an entire molecule from place to place; present in liquids and gases

Vibrational Motion – movement of atoms within a molecule toward or away from its centre of mass; present in solids, liquids, and gases

Work – a force acting through a distance; work is done on a body only when a force causes it to move

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Dedication

To Geoff,

Thank you Geoff for all of your inspiration and help in the writing of this thesis. You were always there for me to express my highs and my lows, and every mood in-between over the past three years. It is with deep sadness that I mourn your passing on July 14, 2010. I will always remember your friendship and guidance towards keeping me on the path to successful completion

Chapter 1: The Introduction

1.1. A Beginning

Instruction in chemistry generally aims to achieve two goals: the acquisition of a body of organized knowledge, and the ability to solve problems (Heyworth, 1999). Educators also consider attaining sound understandings of scientific concepts an important major objective (Jasien & Oberem, 2002; Lemke, 2004). Gabel (1999) describes the complexity of chemistry and lists several barriers to students' understanding of chemistry concepts: chemistry instruction occurs primarily on the symbolic level, the unfamiliar materials frequently in operation in the laboratory, the use of complex language, and the structure of the discipline itself; in effect, the way instructors scaffold the instructional levels of the concepts. As classroom instruction occurs predominately on a very abstract or symbolic level, research indicates that students have trouble using the microscopic level to explain the macroscopic level (Heyworth, 1999). This means chemistry becomes difficult to understand without the use of analogy or metaphor to aid in concept development. Students have difficulties with ideas that do not fit their world experiences and therefore form new ideas (Lewis & Linn, 2003). All conceptions are conceptions; some are considered scientifically acceptable, others are not. Ideas inconsonant with, or contradicting the meanings established by the formal scientific community, are labeled as alternate conceptions or misconceptions (Mulford & Robinson, 2002). Gabel (1999) draws attention to the occurrence of many alternate conceptions found within chemistry and relates how widespread the problem has become. Chemical education researchers have spent a great deal of time and effort determining how students construct scientific concepts of chemistry, and have documented the many difficulties that occur with students having to change faulty prior conceptions (Brookes, 2006).

In order to improve education in the chemistry classroom and laboratory, instructors need to understand, and be aware of, how learning is taking place. I argue that students need to be constantly engaged in constructing scientifically accurate chemistry concepts and changing any inaccurate prior conceptions about how the real world operates. I consider it important to challenge students' preconceptions, their scientific beliefs, and certain events that have become part of how they see the world. As instructors our conceptual knowledge broadly encompasses specific individual cognitions, beliefs, experiences, and skills integrated in character (Frederik, Van der Valk, Leite, & Thoren, 1999). For example, one way students process new information is definitely affected by the setting and the social context in which they learn. Students in the 21st century acquire knowledge in many different ways, such as by internet, textbook, or lab inquiry. As information grows in this century, there is a need not only to learn the basic scientific concepts but also to become increasingly specialized. I suggest that in the classroom, due to students' and instructors' alternate conceptions, many chemistry concepts are not clearly understood. I argue definitions and explanations need to address specific terms and concepts with greater clarity and precision. Kruse and Roehrig (2005) demonstrate that although chemical education research has identified many common alternate conceptions, most chemistry instructors are not aware of the alternate conceptions, nor do they utilize research to counteract or reduce them in the classroom or laboratory. I posit that there is much that could be improved on the part of instructors which will help students' conceptual understandings; if better understood, conceptual change constructs and perspectives may potentially provide a powerful framework for significantly improving instructional practice. If instructors' ideas are better articulated there will be less confusion in the minds of students which I consider key to establishing a productive mode of reasoning in students.

This research study focuses on the particular concept of 'heat'. Although there are considerable conceptual difficulties associated with this topic, there is agreement among science educators on the importance of choosing the teaching of energy as a focus of interest in the science curriculum. Understanding the heat chemistry is pivotal to a meaningful comprehension of many other heat-related scientific concepts, such as temperature, kinetic energy, and work. Moreover, the arduous development of the concept of energy, especially heat, is a good example of concept building and evolution in science (Domenech, Gil-Perez, Gras-Marti, Guisasola, Martinez-Torregrosa, Salinas, Trumper, Valdes, & Vilches, 2007). The heat concept is a theoretical and abstract entity and thus requires a great deal of effort for students and instructors to attain comprehension. Studies do indicate that students frequently exit chemistry courses with inaccurate conceptualizations of heat (Mulford & Robinson, 2002; Niaz, 2006).

In this chapter I state the problem below that initiated this research study by first describing the broad issues of alternate conceptions in chemistry education, with a specific emphasis on the heat concept. I also describe the assumptions that underlie this investigation and provide a thesis overview briefly discussing the content of each section.

1.2. The Problem

Research has shown that chemistry students have many alternate conceptions regarding the heat concept (Gabel, 1999; Sozbilir, 2003). This is a problem because one of the difficulties in comprehending heat is there is no universal definition of exactly what heat is that all chemists agree on (Slisko and Dykstra, 1997). The generally accepted qualitative definition for heat is that heat energy is transferred from one system to another solely by virtue of a difference in temperature with temperature considered a measure of the average kinetic energy of the molecules in a system (Tripp, 1976; Pushkin, 1997).

I investigate and determine whether or not chemistry instructors may be a source of these particular alternate conceptions by examining and analyzing the vocabulary and language instructors use as they teach the heat concept. In this study the term 'instructor' is used as congruent or equivalent in meaning to 'teacher'. To support my study I also compare and contrast the language several chemistry textbooks use for the manner in which the heat concept is taught. The data I gather from a representative sample of chemistry instructors and textbooks intends to show whether or not scientifically accurate constructs are effectively generated from these two sources of information**.**

1.3. My Assumptions

I assume that language is a proper and logical means of expression representing chemical knowledge in the classroom. I demonstrate that spoken language by chemistry instructors, and written language in chemistry textbooks are very important to the learning process; all of which is especially crucial in the building of the correct heat concept. It is my understanding that the language instructors use is an acceptable and genuine representation of concepts in chemistry.

I further present that language by itself is often insufficient to express desired scientific meanings to students. I argue that meaning is built, and developed, from a variety of representations rather than conveyed by strict literal means. Learners, therefore, understand concept meaning from the linguistic representations they read and hear. Abstract concepts, such as heat, are built by constructing the necessary equivalences obtained through words, symbols, images, and actions (Lemke, 2004). However, intuitive alternative conceptions for scientific phenomena are often invoked behind the use of the scientific words and phrases used in chemistry classes (Lewis & Linn, 2003). I argue that chemistry instructors must take care not to be conduits of alternate conceptions through the misuse of metaphors and analogies frequently used in instruction.

1.4. The Thesis Overview

In this first chapter I outline key areas of the research study. In chapter two, the literature review, I begin with a discussion of how chemistry concepts are developed. There are many different representations of chemistry ideas from the abstract to the concrete level. It is very difficult for learners to assimilate, coordinate, and move easily from these different representations in order to create accurate scientific understandings (Heyworth, 1999; Kruse & Roehrig, 2005). Based on my teaching practice, as well as published research studies (Warren, 1972; Harrison, Grayson, & Treagust, 1999; Taber (2000b), students and instructors of chemistry find it difficult to represent the abstract ideas and chemical processes in different ways and navigate between the different representations.

Talanquer (2006) argues that many teachers do not adequately analyze or reflect on students' preconceived ideas. The classroom instruction becomes one of assessment – comparing students' answers with provided school or institution-based answers. Answers are judged right or wrong with little analysis of the thinking behind the response diverting teachers from using student thinking to inform their practice. It is therefore critical from an instructor's viewpoint to identify learners' alternate conceptions to help reduce them and build accurate scientifically constructed concepts and understandings in chemistry. I argue for the identification and reduction of alternate conceptions in chemistry education so as to have learners build concepts which are in agreement with the scientific community. Good instructors will help learners improve the nature and operation of knowledge constructs to make them more scientifically accurate.

I then explore the diversity of constructivism. Constructivism is often considered a set of beliefs about knowledge which begin with the assumption that a reality exists but cannot be known because of the fallibility of human experience; learning is a social process of making sense of experience in terms of knowledge already possessed (von Glaserfeld, 1989). This broad diverse theory for building concepts is frequently utilized in chemistry education to explain learning. Constructivism, with all its differing philosophies and ideologies, emphasizes the necessity for active participation by the learner, the social nature of learning, and a progressive intent (Phillips, 1995). My view is that the surrounding real world, or nature, influences and constrains our thinking and knowledge constructing abilities. My teaching practice, also informed by educational research (Jasien & Oberem, 2002; Sozbilir, 2003), has shown that students enter chemistry classes with a multitude of pre-conceived ideas about how the natural world operates. Many of these preconceived ideas differ from currently accepted scientific theories and practices. Problems arise when learners try to assimilate their preconceived ideas into existing conceptual frameworks. It is important for instructors to teach using the most current scientifically accurate ideas available. As well, conceptual change must be carefully and thoughtfully considered. I have noticed from my teaching experience that if you force learners to change their minds too quickly, they cannot readjust everything, and they will attach blame to the instigator (instructor) for their discomfort, sense of confusion, and loss of balance. The affective domain of learning is compromised and actual informative learning is frequently stunted or halted.

Next, in the literature review, I identify and examine some alternate conceptions instructors may bring to their chemistry instructions and discuss how these misconceptions might be transferred to their students during the teaching process, especially if instructors are not aware of the problem. Specifically I investigate the terminology, problems and limitations, nature, measurement, origins, and lists of alternate conceptions. I suggest that probably the greatest source of confusion about the concept of heat centres around the language and semantics used in discussing the topic. Scientists are not in agreement over the meaning of many different heat-related terms used in explaining the concept (Slisko & Dykstra, 1997). Historical case studies and narratives provide one mechanism for showing how the concept of heat evolved over time (De Berg, 2008). As we teach heat from an instructor's perspective we are relying on the perspective we used when we learned, in the past, about the particular conception with often the classroom textbook aiding our purpose. Veiga, Duarte, and Maskill (1989) reason that common alternate conceptions will not be eliminated if the teacher unintentionally reinforces a faulty idea.

Textbooks have long been considered a major influence in shaping the practice of science-education instructors. Efforts to improve the quality of textbooks and, towards bringing about conceptual change, stem in part, from a widespread belief that students have difficulty learning from science textbooks, for example, comprehending the written language is a difficult process (Gabel & Bunce, 1994). Teachers rely on textbooks for knowledge and the books serve as a main resource for instruction; I suggest students experience considerable confusion impeding coherent learning if these books display and record significant variations and discrepancies in scientific definitions and explanations. In the literature review I summarize research which surveys specific chemistry textbooks by analyzing terminology, ontology, and coding contained within the texts pertaining to the heat concept.

In addition to textbooks there are other educational resources available for improving instructors' teaching of the heat concept. The use of examples, historical studies, metaphors, analogies, models, graphical representations and animations should greatly help the process of building scientifically accurate concepts in chemistry.

In this research study, as described in chapter three, I use grounded theory as a methodology for uncovering some instructor-held concepts specifically pertaining to heat and temperature. Grounded theory provides a valuable methodology for determining the accuracy of concepts held by learners through inductive qualitative analysis. The grounded theory method stresses discovery and theory development, not verification of preexisting theories, which is important for accurate concept building (Charmaz, 1994). Systematic application of grounded theory may lead to more accurate representations of abstract analytic levels. My rationale for using this type of methodology begins with the notion that grounded theory avoids constricting definitions; it permits a process to occur of moving from very specific circumstances to more general ideas of a wider context which offer testable predictions verifiable by traditional and statistical means. Theories emerge from the qualitative data grounded in the lived and practical experiences of the chemistry instructors. Taber (2000a) describes grounded theory research as not traditional in nature; in the work there are no particular steps of a research plan, data collection, analysis, and reporting, but instead ideas evolve in increments, organically guided by the principles of emergent fit, theoretical sampling, and saturation. Theoretically, grounded theory methodology makes the assumption that there is little to no previous knowledge with the subject matter inherent and builds from that viewpoint. I make the strong effort to enter into this research study with as few preconceptions as possible and discuss both the assumptions and limitations of the study. Chapter three further describes the method of this research study, details the design of the study, the data collection and analysis techniques, as well as theory generation and refinement.

In Chapter four, I draw together the literature from Chapters two and three as I examine the compiled data generated from the study. I process and analyze the information gathered, and through the use of charts, tables, and figures tabulate this material for ease of examination. In support, I provide an accompanying analysis of several specific textbooks used in chemistry classes to identify how the heat concept is presented with vocabulary and grammatical expression highlighted. I determine that chemistry textbooks, as one major source of concept representation, do contain faulty ideas. Research has shown that the textbooks used in science courses from middle school to college level, including discussions of heat, present material either incorrectly or superficially, such as not expanding on the phrase 'the ideal gas state is imaginary' (De Berg, 2006). This very likely creates confusion in students' minds. The text is a tool enabling students to construct meaning. For this reason, understanding the chemistry text requires careful reading and comprehension. I also provide examples of instructor specified resources in this chapter, such as laboratory experiments, which are important ways to present abstract and concrete concepts to students for building strong and accurate thermal concepts.

In Chapter five, I summarize the results of the research study and suggest how this study can improve chemistry education by offering ideas and resources to promote and effect conceptual change. These suggestions provide important implications for instructional practice for chemistry educators and textbook writers, as well raising questions, and giving direction for future research.

It is important for chemistry instructors to provide meaningful learning opportunities for students. They need to encourage students to explore and evaluate their conceptualizations. I argue that instructors identify and examine any alternate conceptions they might have in an effort to inform their practice and find ways to instructionally counteract misconceptions before passing these incorrect ideas on to students. Conceptual change is considered a process of coming to view one theory or model as having more explanatory power than others; it can be explained as a long-term gradual shift in which several alternative explanatory principles are better choices (Taber, 2001a). I suggest instructors reflect upon necessary changes in any transformative thinking they undergo and be able to better articulate the new meanings of their knowledge to students. There is room for improvement in building new understandings, and in effecting conceptual change from existing alternative conceptions to accepted scientific meanings.

Chapter 2: The Literature Review

In this chapter I review a selection of the literature related to my research problem concerning the investigation of the alternative conceptions instructors might have accrued in the teaching of the *heat* concept, and the role that textbooks might play. This review consists of seven sections. In the first section I discuss the problem of conceptual development in science specifically within the discipline of chemistry. In the second section I distinguish between several explanations of constructivism in education and identify my personal epistemology. For the third section I provide a brief overview of alternate conceptions and misconceptions in science, particularly for chemistry. In the fourth section I present a review of the development of the heat concept linguistically and historically, including a view of conceptual change development. I describe several textbook analyses regarding heat in the fifth section, and address animations and graphical representations pertaining to instruction of the thermal topic in the sixth section. In the final section I summarize and theorize on the need to examine conceptual change from multiple perspectives, identifying the evidence, and the use of teaching materials and approaches to effect successful change in science education.

2.1. Concept Development

Chemistry is a very complex subject and, as such, often uses a threefold approach to representing matter: the macroscopic, the particulate world, and the symbolic level (Gabel, 1999). The macroscopic level is a concrete one corresponding to observable objects, their properties, and the terms used to describe them, such as at room temperature water exists as a liquid and iron is a solid. The particulate or microscopic level is the world where particle interactions occur. This level involves the concepts, theories, and principles needed to explain the macroscopic level observations. An example of this level would be the concept of bonds breaking as oxygen changes phase from solid to liquid to gas with increased temperature. The symbolic level consists of conventions used to represent the various phenomena, and deals with formulae and mathematical calculations. For instance, the symbolic representation used for water is H_2O representing two atoms of hydrogen bonded to one atom of oxygen for every molecule of water formed.

Many scientists and science educators operate across all three levels of thought easily, and switch from one mode to another with little effort. The primary barrier to understanding chemistry, however, is not the three-level representations, but that classroom instruction occurs predominately on the most abstract or symbolic level. Past research indicates that students have trouble using the microscopic level to explain and make predictions about the macroscopic level (Heyworth, 1999). Students look at new learning materials through the lens of their pre-instructional conceptions and often find it incomprehensible. Chemistry becomes inexplicable without the use of analogies or models (Gabel, 1999).

Ever since the classical studies of Piaget there has been interest in the conceptions of science held by children (Osborne & Wittrock, 1983). Students create meaning from informal instruction, their own experiences of the world, and their beliefs and theories about the world they live in. These meanings are all linked to form sets of understandings called concepts. Concepts may contain appropriate or inappropriate linkages. Because links are hard to build, students' knowledge is often fragmented, with students tending to rely on systematic procedures involving mathematical operations that use a finite number of steps to produce a definite answer (Nakhleh, Lowrey, & Mitchell, 1996). For example, using Le Chatelier's principle, it is possible to deduce which side of chemical equilibrium is being favoured when a stress is put on the system by simply counting the number of moles of gas on each side of the equation without true understanding of the nature of the principle. As Gabel (1999) explains, many chemistry concepts are abstract. If there is nothing in long-term memory to which a new concept can be related, then it is either stored as a single entity, or not stored at all. Hence, if something does exist to which the new concept can be related, then learning occurs. Meaningful learning, or experiential learning, as opposed to memorizing definitions and using terms without comprehension, is considered more profound due to the integration of concepts and beliefs. In a broad range of reviewed work Gilbert and Watts (1983) discuss the relationship of various descriptors to particular meanings for the word 'concept'. They examine epistemological traditions, general patterns, and modeling pertaining to concept development. The prevailing view is that alternate ideas or interpretations, often classified as misconceptions, which students bring to their study of chemistry, are predominately a hindrance to meaningful learning. I maintain meaningful learning involves more than just understanding a concept but also encompasses remembering, applying, analyzing, evaluating, and creating ideas from the concept-base.

Based on my teaching experience, the way in which learners build concepts is very important in science education. Instructors and students think with concepts. Concept development and the ability to interpret and explain natural phenomena are directly affected by how concepts are constructed with the large possibility of faulty conceptions being lodged in learners' minds. There are substantial educational implications as instructors and students attempt conceptual change. Conceptual change theory, which involves using conceptual change texts accompanied by models and demonstrations, was derived from the theories of Piaget, Kuhn, and constructivism (Driver, 1981). It has been their position that learner's misconceptions need to be confronted by the learner in order for learning to take place. The teacher's role is, then, to produce 'cognitive conflict' so that accommodation can occur (Justi & Gilbert, 2002).

2.2. What is Constructivism in Education?

Constructivism is a theory, paradigm, or model intended to describe learning. Constructivist pedagogy is considered one method of concept building. It is a metaphor for learning, and likens the acquisition of knowledge to a process of building or construction. As a theory of learning its central claim is that human knowledge is acquired through a process of active constructions. Constructivism emphasizes the understanding aspect of learning extending beyond plain new knowledge absorption. It is a theory underpinning research programs in education, involving misconceptions and alternative frameworks, as well as curriculum development (Matthews, 1993, 2000).

Constructivism is a heterogeneous movement consisting of many varieties such as contextual, dialectical, empirical, information-processing, methodological, moderate, Piagetian, postepistemological, pragmatic, radical, realist, social, sociohistorical, and sociocultural. The constructivist psychologists theorize about, and investigate how, human beings create systems for a meaningful understanding of their worlds and experiences. Besides its utility in philosophy, and in education, constructivism may refer to individuals or to groups. It can refer to a world-view, a particular philosophical orientation, a sociological viewpoint, a political stand, or a personal belief. Differing areas of commonality and divergence occur depending on how educators choose to carve out a particular category of construction. Constructivist psychologies have not evolved into a single, coherent, and theoretically consistent orientation. Given numerous theoretical differences, there is not even agreement among constructivist psychologists that it is desirable to arrive at a singularly recognizable orientation (Raskin, 2001). Ironically, the widespread manner in which the term is used creates confusion and controversy in many areas of education. The term constructivism means different things to different people. Especially in science education is a diverse movement with no clearly defined boundaries. Constructivism as a theory of knowledge, and as a theory of teaching and learning, is so central to modern educators that Matthews (2000) calls it a grand and unified theory for education. Phillips (1995), in his discussion of the many faces of constructivism, likens it to a 'secular religion'. Constructivism might be thought of as a broad 'church' composed of many sects with each of these sects having some distrust of the other's ideas. However, most sects emphasize the learner's active participation, recognize the social nature of learning, and are progressive in nature. I think that in terms of constructivism, it is nature with all surroundings and past experiences that influences knowledge-constructing activities of both instructor and student. This allows us to openly identify our alternate conceptions and hopefully reduce and eradicate them. Then, as instructors, we can improve our teaching skills within the classroom to try and reach and include, thus engaging all students with the nature and openness of our scientific knowledge-constructing communities.

2.2.1. General Definitions and Principle Claims

Many researchers have extensively reviewed the literature tracing the roots and development of constructivism (Cobern, 1993; Fox, 2001; Raskin, 2001; Taber, 2006a; Terwell, 1999). The definition of constructivism, a practical idea, is implicit in its name. Fox (2001) summarizes the claims which, held together, define constructivism as:

1. Learning is an active process.
2. Knowledge is constructed, not innately or passively absorbed.

3. Knowledge is invented, not discovered.
4. All knowledge is personal and idiosyncratic.
5. All knowledge is socially constructed.
6. Learning is essentially a process of making sense of the world.
7. Effective learning requires meaningful, open-ended, and challenging problem-solving.

Initially, constructivism was set up in opposition to the more traditional views of education. The constructivist learning model is often contrasted to the transmissionist, or objectivist, learning model which views the teacher or instructor as the source of knowledge and students as passive receptacles of this knowledge. The objectivist learning model emphasizes learning by receiving information, especially from instructor and textbook, to help students encounter facts and learn well-defined concepts. From the constructivist point of view, learning is the process of making sense of something in terms of what is already known. It is an active process in which learners construct knowledge in a way that makes personal sense. It is also a subjective process as learners draw on their own background experiences. Howard, McGee, Schwarz, and Purcell (2000) claim that, in general, the constructivist learning model emphasizes the creation of active learning environments permitting critical thinking, discovery, and collaboration. From a constructivist's point of view language users must individually construct meanings of words, sentences, and stories. But it is not a means of transferring information; language must have meaning and not be a source of it (Yager, 1991).

Fox (2001) argues that the great variety of constructivist theories differ little from common sense empiricist views and provide misleading and incomplete perspectives of human learning. Although there are many variations, the common thread of constructivism is that it is individual-centred, experienced-based, and relativist. However, its relativism needs to be distinguished from other relativisms in which the goal of science as a search for truth about the world is accepted, and it is then asserted that we cannot know from different accounts which one is actually true or better. In contrast, for most constructivists, our knowledge does not tell us about the world at all, it tells us about our experiences and how they are best organized (Matthews, 1993). Constructivism seems to imply that making sense of things is a natural cognitive state which, in turn, makes learning satisfying. I suggest that this implication does not take into account the natural digressive, perceptual, and incidental learning that occurs unconsciously from individual experiences.

Taber (2006a) follows the influence of constructivism in science education. Kuhn's dominant paradigm illustrated for decades that science progressed by a series of scientific revolutions providing transitions between discrete and mutually exclusive research traditions. Kuhn (1970) proposed the idea that we all know the world through conceptual goggles or lenses. These lenses, or paradigms, which determine how we know the world, are defined by what we know and limit the way in which we perceive reality. Taber (2006b) argues that the constructivist movement has an incoherent position, makes use of invalid constructs leading to the formation of alternative conceptions, marginalizes the social perspective, reduces the efficacy of some teaching approaches, and monopolizes many resources in the field. De Berg (2006) reasons that as constructivism has acquired a vocabulary of its own and therefore, on the surface appears different, but it is not different and does not appear to be a foundational base for studies in the teaching and learning of chemical concepts. Some chemistry educators adopt some of the more controversial aspects of constructivism as a lens for understanding their particular research studies but the majority adhere to a simple view of ‘learning by construction’, or ‘student-centred learning’ which De Berg maintains is not unique to constructivism. Bernal (2006) suggests that the confusion that concerns science educators results not from using the term in different senses, but comes from the philosophical confusion starting with educators moving from psychological claims about the way knowledge is acquired to epistemological conclusions about what can be known.

2.2.2. Several Key Theories of Constructivism

(i) Personal, Radical, and Social Constructivism

Raskin (2001) clarifies similarities between three key constructivist psychologies: personal construct, radical, and social constructivism. All constructivist psychologies share the belief that none of the many ways of understanding that people have developed provide a purely objective view of the world. All constructed meanings therefore reflect a point of view. Personal constructivism, or making your own meaning, describes people organizing their experiences by developing bipolar dimensions of meaning, or personal constructs. These hierarchically interrelated constructs are then used to anticipate and predict future events. The metaphor used is the knowing individual as a personal scientist continually testing their personal constructions. Radical constructivism, or your own private take on reality, emphasizes the ability of human beings to use the understandings they create to help them navigate life, regardless of whether or not such understandings match an external reality. Social constructivists have an aversion to the notion of an isolated knower; knowledge is negotiated between people within a given context and time frame. People are not considered to have any sort of stable and essential personality. Consequently, the role of language is considered critical in social constructivism (Raskin, 2001).

(ii) Experience-based and Discipline-based Constructivism

De Berg (2006) examines what he terms the distinction between the more contemporary views of experience-based constructivism and discipline-based constructivism. He argues that many strategies developed to increase student participation have been successfully implemented without mentioning the word constructivsm or any call to its philosophy. De Berg believes that experience-based constructivsm fails as an epistemology for chemistry as a subject because concepts, conventions, and idealizations are products of the human mind rather than immediate sense experiences. De Berg further advocates that experience-based constructivism is powerless to inform the origin of such concepts in chemistry and while discipline-based constructivism talks about idealized concepts, such as gas law development, it does not offer any unique perspectives that cannot be obtained from other models.

(iii) My Epistemology – Pragmatic and Practical Constructivism

Gordon (2009) lays out a pragmatic constructivist discourse that synthesizes some ideas that constructivist thinkers usually keep separate. He defines pragmatic as a reference to a way of knowing that comes out purposefully changing the environment and then reflecting on this change. I suggest that Gordon proposes more than just a critique of traditional models but, instead, provides an educational discourse that offers some concrete guidance and advice for instructors. Gordon's view is important because most constructivist discourses were not originally conceived as 'educational' discourses and therefore do not provide practical recommendations for educators. I think there should be a mutual interaction between educational theory and practice with each informing, and being influenced by, the other. At this moment constructivism becomes a type of relativist discourse with no clear and coherent claims or evidence of any new paradigm overthrowing its orthodox model (Taber, 2006a).

I suggest that the instructor's role in a practical constructivist driven class is to provide multiple opportunities for students to talk about, and reflect on, their learning and thinking. However, I acknowledge that this frequently may be difficult to achieve because both instructor and student likely bring to the discussion radically different conceptual frameworks. Unless these conceptual differences are identified, actively discussed, and dissected, meaningful learning will not take place. I think that instructors need to realize the importance of learners trying to make sense of new lessons in terms of their pre-existing knowledge. Learning is difficult and should be a struggle to get beyond existing knowledge. Practicing our use of concepts, skills, and strategies to make performance easier helps in the elimination of errors, and aids in the transfer of limited powers of consciousness away from routine competencies (Fox, 2001).

Constructivism recognizes that motivating learners to engage in understanding a new topic requires more than just promoting the new learning to be accomplished. Students need to be allowed to reveal their pre-existing knowledge about topics, such as heat and temperature, in order to expose possible alternate conceptions. I maintain that activity alone is not the solution, in addition, instructors should find out what really interests, motivates, and is of value to learners to justify the progressive tone of constructivism. The problem is that learners may find it difficult always to see a purpose in learning and understanding new concepts in a lesson, as well as the need to eradicate any alternate conceptions. Constructivists may disagree about specifics but all varieties of constructivism challenge psychologists to refocus their attentions on the critical importance of the human meaning-making process.

Cobern (1993) contends that when consultation is utilized constructivism provides a promising conceptual framework for research and practice. He explains that a constructivist theory lends itself readily to practical application; one of the attractions of its use in science education research is simplicity. Science makes more sense because it is attempting, with some success, to get to the truth about the world (Matthews, 1993); the challenge to use constructivism appears to be growing in chemical education (Scerri, 2006).

2.3. Alternate Conceptions in Science

I argue that learning is an active process, and what students do with the facts and ideas with which they have been presented depends, to a very high degree, on what they already think and believe. A key component of an effective educational strategy is being able to recognize, and work with, students' differing ideas and conceptions (Nakhleh, Lowrey, & Mitchell, 1996), as well as determining and acknowledging the importance of what the learner already knows (Erickson, 1979). During the last four decades a large body of research has described concepts held by science students at different levels. A considerable amount of this research illustrates that relatively young children develop intuitive ideas and beliefs about natural phenomena. As they learn more about the natural world they develop new or revised concepts based on their interpretation of this new information from the viewpoint of their existing ideas and beliefs (Bartow, 1981; Gabel, 1999; Novak, 2002). I see learners of all ages as active constructors of knowledge through their interactions with the physical world inside their social, cultural, and contextual environments.

2.3.1. The Terminology

Mulford and Robinson (2002) define 'alternate conceptions' as concepts, held by students, that are inconsistent with the consensus of the scientific community. There has been much controversy as to whether to define student conceptions that are not in accordance with those held by scientists as preconceptions or misconceptions. Pushkin (1997) defines a 'pseudoconception' as a special kind of alternate conception caused when chemistry students are forced to use terminology they do not fully grasp. It is implied that once the 'proper' meaning of a scientific term is agreed upon by experts, and all others are informed of the proper meaning, then pseudoconceptions will be avoided or reduced. I think this is not necessarily true.

Lewis and Linn (2003) disagree with Pushkin's (1997) premise that there exists a well-defined scientific knowledge waiting to be used. This view suggests that terminological diversity, when contextualized in analogy and metaphor, contributes to an instructionally rich discussion. Lewis and Linn (2003) imply that meaning of terms is varied, and always has to be negotiated. Because science claims a coherent view of the world, its terminology is expected to show a logical structure with some internal consistency. If our terminology leads to confusing conceptual constructions when such simple logic is used, then it is crucial to frequently remind students to think logically and make sense of what is written or spoken in that terminology, for example, by instructor modeling. I believe, however, that students require instruction in this pursuit because they may not know how to necessarily do this.

I suggest that word meaning and usage can also be a significant source for alternate conceptions. Pristine conceptual clarity is required for successful critical thinking. Lemke (2004) contends that language itself is the most pervasive system of semiotic resources, and the ways in which scientists use specialized languages, and use common language in specialized ways, index the discourses of the communication of scientific disciplines. Semiotics pertains to the study of how we make meaning using the cultural resources of systems of words, images, symbols, and actions. He argues that the essential languages of visual representation, mathematical symbolism, and experiential operations in chemistry are goals of science meant to empower students to use them all in meaningful and appropriate ways with the ability to functionally integrate them into scientific activity. I agree with Lemke's argument; if the goal of chemistry education is to empower students to use the forms of reasoning and action that constitute scientific practice then it is important to pay more strict attention to our teaching of the language of chemistry. This view also informs the work of Slisko and Dykstra (1997) and of Brookes, Horton, Van Heuvelen, and Ektina (2004).

Characteristics of alternate conceptions are summarized as: being resistant to change, persistent, well-embedded in an individual's thinking processes, and difficult to extinguish even with instruction designed to address them (Canpolat, Pinarbasi, Bayrakceken, & Geban, 2006). Tan, Taber, Goh, and Chia (2005) report that alternate conceptions are considered to be significant and common if they are found in at least ten percent of a student sample.

2.3.2. The Problem and Limitations with Alternate Conceptions

Alternate conceptions frequently interfere with further learning, making it difficult for students to see the greater vision, realize links among science concepts and principles, and apply these principles meaningfully to daily life, or scientific inquiry within the classroom. Novak (1998) distinguishes between rote learning and meaningful learning. Rote learning is where new knowledge is arbitrarily and without substance incorporated into cognitive structure. Meaningful learning and long-term memory occur when the learner chooses conscientiously to integrate new knowledge with previously possessed knowledge. Nevertheless, if students must construct their own understanding of new concepts, and must build this new understanding out of the conceptions they already possess, then it is inescapable that they will need to draw on their alternative conceptions for pieces they can rearrange and reuse to form new concepts. These are concepts initially accepted by students as close enough to scientifically accepted ideas to be useful in transitioning to the use of the latter. Teachers often treat misconceptions as though they are incorrect, illogical, unsubstantiated, or ludicrous ideas (Bartow, 1981). Posner, Strike, Hewson, and Gertzog (1982) and Taber (2000b) maintain that instructors need to persuade students that the scientific viewpoint is more fruitful and accurate than alternative conceptions.

Ozdemir and Clark (2007) contend there is no single truth to explain the complex processes of conceptual change and naïve knowledge structure for students. The researchers compare and contrast two competing theoretical perspectives regarding knowledge structure coherence, that is, the perspectives of knowledge-as-theory and knowledge-as-elements. Knowledge-as-theory (more historically supported by the literature) states that a learner's knowledge is represented as a coherent unificed framework of theory-like character. It is characterized to involve coherent structures grounded in persistent ontological and epistemological commitments which are used to support revolutionary change in knowledge structure through various mechanisms. For example, conceptual change may occur through assimilation and accommodation, including paradigm shifts. It is acknowledged that learners do have a small number of well-developed coherent naïve theories based on everyday experiences which enable them to make predictions and provide explanations. If certain specific conditions are met, the learners will become dissatisfied with existing conceptions when the conflicting examples are introduced. The learner then abandons existing alternate conceptions and accepts more scientifically appropriate alternatives.

In contrast, knowledge-as-elements or pieces is considered an ecology of quasi-independent elements. This perspective hypothesizes that naïve knowledge structures consist of multiple conceptual elements such as phenomenological primitives (p-prims), facts, and mental models which at various stages of development and sophistication are spontaneously connected and activated by situation relevance. P-prims are hypothetical ways of explaining how students can provide answers to questions where they have no pre-existing answers in place, and for explaining the origins of more complex and stable concepts (Taber, 2006b). From this perspective, Ozdemir and Clark (2007) describe conceptual change as involving the revision and reorganization of elements or ideas to strengthen a network. If a learner's intuitive knowledge is elemental in nature, instructions should focus on how those elements are activated in appropriate contexts. Instructors first make students aware of their central pieces of knowledge and then allow students to use them in appropriate contexts. Taber (2006b) argues for a model of cognition that encompasses both perspectives towards a progressive constructivist program in learning science. He suggests knowledge-as-pieces and the alternative concepts or knowledge-as-theory can co-exist as each has more power with a particular concept or idea.

Based on my practice, I suggest that instructors must work towards replacing students' naïve ideas with a 'correct' scientific understanding within the classroom. It is also normal that instructors' knowledge will not match frontier levels of knowledge and understanding and a school curriculum often presents a further simplification of the science as the version to which pupils should work. The development of hybrid concepts initiates change or operation with a mixture of new and established thinking (Taber, 2000b). It is hoped that the student will embrace the 'new' concept when the new idea makes more sense than the alternative, and assumed that the change proceeds 'logically'.

The literature supports the difficulty of changing alternate conceptions and the slow pace of conceptual change (Gabel, 1999). In addition to students' alternate conceptions teachers have often not been exposed to situations which challenge the validity of their constructed ideas, and thus may be unaware of their own alternate conceptions. The problem is compounded because teachers' alternate conceptions may in fact be directly transmitted to students during the act of teaching (Kruse & Roehrig, 2005; Taber, 2002). Veiga, Duarte, and Maskill's (1989) test whether teachers are inadvertently reinforcing wrong ideas to students through the language they use in instruction. They indicate that common alternate conceptions found in students' work, such as understanding the heat concept, are embedded in the metaphors and analogies teachers employ in class. I constantly worry that, as a practicing chemistry instructor, I might unintentionally be transmitting alternate conceptions to students during content instruction – an experience that underpins this inquiry!

Taber (2001b) examines why motivated students, in appropriate learning environments, still fail to learn effectively from keen, able, and well-organized teachers. He provides a constructivist model to identify learning impediments. He suggests teachers identify students' present impediments and be aware of potential learning obstructions in order to arrange the learner's present content to match their inherent cognitive structures. I think it is important for instructors to be aware of a possible mismatch between students' assessed prerequisite knowledge and actual conceptual structures.

2.3.3. The Nature of Alternate Conceptions

(i) Identification and Measurement

"Alternate conceptions play a larger role in learning chemistry than simply producing inadequate explanations to questions" (Mulford & Robinson, 2002, p. 739). If students, and presumably instructors, encounter new information contradicting their alternate conceptions, it may be difficult for them to accept the new information because it seems wrong. New information and ideas which students encounter are reinterpreted and rearranged to fit within a mental framework formed from preexisting conceptions, and all subsequent knowledge is built upon this framework. As anomalies do not fit their expectations, new information may be ignored, rejected, disbelieved, deemed irrelevant to current issues, reinterpreted in light of the students' current theories, or accepted with only minor changes to the concepts of students (Mulford & Robinson, 2002). Several researchers who agree with this taken-for-granted theory include Chinn and Brewer (1998), Gabel and Bunce (1994), and Herron (1996).

Concept maps may be useful in identifying alternate conceptions (Novak & Musonda, 1991). One indicator of alternate conceptions would be incorrect linkages forming invalid propositions, such as, stipulating energy is involved in all changes that can be measured. Most of the literature I surveyed traditionally describes, reviews, and organizes research on alternate conceptions in chemistry by topic or subject. Unfortunately, this 'inventory approach' makes it difficult for instructors and researchers to identify any common assumptions, or patterns of reasoning, that may be guiding or affecting students' thinking about chemical phenomena. However, a number of science education researchers have done some valuable work in this area. This critique of alternate conceptions is well supported by the studies following next.

Birk and Kurtz (1999) designed and administered a two-tiered recall/reasoning multiple choice test to uncover misconceptions for high school and first-year university chemistry students regarding the concepts of molecular structure and bonding. A number of alternate conceptions were identified. The study also tracked the disappearance of these alternate conceptions over ten years of student experience, along with the development of accepted conceptions.

Mulford and Robinson (2002) were interested in developing an instrument to measure the extent of beginning students' alternate conceptions about topics found in the first semester of many traditional general chemistry courses. They were also interested in how changes occurred in alternate conceptions after one semester in these courses. To this end, they developed a 'chemistry concepts' multiple choice inventory instrument designed to show the extent of acquired alternate conceptions.

Kruse and Roehrig (2005) also designed a 'chemistry concepts inventory' to assess chemistry teachers' conceptions within a large urban district. The findings indicated parallels between instructors' alternative conceptions and those of first-year college students. Also, quantitatively, their findings indicated that in comparison instructors generally scored higher than their students on all test items with a similar distribution of alternative conceptions and most commonly incorrect items. Kruse and Roehrig qualitatively analyzed contextual factors contributing to instructors' conceptions, such as degree major and credential status. I agree with the belief that instructors may be unaware of their own alternate conceptions. However, I frequently observe in my teaching practice that groups of students holding alternative conceptions and struggling with discrepant events are able, with guidance, to 'discuss' their way into a very different and stable scientific conception.

(ii) Common Sense Origins

My survey of the literature finds that most researchers note it is difficult to discern the origins of many alternate conceptions. The thinking also suggests 'common sense concepts' may lie beneath expressed student alternative conceptions but which students may not even be able to articulate. Common sense reasoning is grounded in a set of presuppositions about the surrounding natural world and relies on mental strategies to make decisions and build inferences based on the information readily available. Taber (2000b) and diSessa (2004) point to the strong preference of most of their subjects for common sense reasoning, everyday analogies, visible effects and changes, and common (non-scientific) word usage. They call for teachers to lead students in critical thinking to the limits of analogies and metaphors. I agree, in that, if things are kept too simple, or inaccurately conveyed, then impediments in understanding scientific concepts will likely occur.

Talanquer (2006), guided by the assumption that a common explanatory framework does exist for common sense concepts, initiated a research project involving analysis of the research literature on alternative conceptions in chemistry. His research was based on the hypothesis that the conceptual difficulties of most science learners result from reasoning based on 'common sense'. Talanquer believes learners' conceptual difficulties result from common sense reasoning characterized by unconscious thought patterns based only on intuition, broad generalization, and very little reflection. Unfortunately, common sense reasoning seems to be responsible for a great number of the alternative conceptions that students hold about the behavior of the natural world, such as students thinking that liquid has filtered through glass when they observe water condensing on the outside of a glass container. Talanquer found that many of the students' alternative conceptions in chemistry resulted from the confident and impulsive action of a crude, limited, and superficial explanatory framework about chemical substances and phenomena. He developed a list of empirical assumptions underpinning alternative conceptions and provided a reasoning heuristic. According to this important study, many of the alternative conceptions in chemistry, as described by the literature, seem to result from the combination of several specific presuppositions. For instance, continuity or believing matter can be continually divided into smaller pieces with each piece having the same properties of the whole object, or essentialism, that is objects having an identifying underlying quality or essence. The use of quick shortcut reasoning procedures are often enlisted to find and select information in an effort to make rapid decisions and inferences. Talanquer derived a working model to help chemistry teachers interpret students' common sense ideas in more comprehensive ways. He does not intend to propose that the complexity of students' thinking in chemistry be reduced to a limited number of assumptions and simple reasoning tools always applied in the same way regardless of context or individual. I agree with Talanquer's argument, an inventory approach analysis of alternate conceptions does not explain 'how' students reason. The development of a common sense explanatory framework would be useful for chemistry instructors because it could be used to identify, understand, and predict possible student held alternate conceptions. I submit this would lead to the formation of better teaching strategies.

2.3.4. The Inventory – a Catalogue

Duit (2004) compiled a broad and lengthy bibliography in an attempt to document research on teaching and learning in science and chemistry with a specific emphasis on constructivist perspectives. The bibliography includes more than 7700 entries based on a collection of papers on students' alternative conceptions. The role of various students' and teachers' conceptions in the teaching and learning process is given particular attention. Horton (2004) organized alternate conceptions by topic, for example, atomic structure, electrochemistry, and heat, and provided criteria for rating the conceptions as key or central. Talanquer (2006) tabulated some concepts based on a common sense explanatory framework. I suggest that reducing the cited literature to a list of alternate conceptions devalues the research. My justification is that a simple list does not provide the origin and development of alternate conceptions, nor does a list provide the means of eradicating any faulty ideas. When considering a list of alternate conceptions, the 'heat' concept is a significant example fraught with problems which I will address in the next section.

I have presented a precisely selected review as the literature on the subject of students' alternate conceptions is extensive, and has been far from completely explored. Researchers continue to discover new alternative conceptions by asking new questions. And controversially, educators and textbook writers continue, inadvertently, to generate new problematic alternate conceptions.

2.4. The Development of the Heat Concept

(i) The Terminology – Language and Definition

Based on my teaching experience, hopefully through a critically reflective process of learning and conceptual change, I have learned that language can be a remarkable source of alternate conceptions for students. I have found that few researchers have considered the possibility that our physical experience may be connectively linked by the language we use to describe the experience. For example, linguistic discussion of the words' heat' and 'temperature' provide rich sources of information for researchers and teachers in science education. Zemansky (1970) suggested that heat and work are methods of energy transfer, and when the flow is over, the words 'heat' and 'work' no longer provide any usefulness or meaning. As a result of these transfers the internal energy of the system has either, increased, decreased, or remained constant, and, once the transfers are over, we can speak only of the internal energy of the system. Warren (1972) specified that heat and work refer only to energy in the process of transfer, and their values are determined not only by the initial and final conditions but also by the route followed. It is incorrect to speak of the amount of heat or the amount of work in a body. By generalization, and the results of many experiments, we can associate a definite internal energy with a body in a given state and recognize that heat is, like work, a process of energy change. The diversity of units of energy and power with the odd conventions relating to their use may be a contributory factor in the misunderstanding concerning the nature of heat. 'Heat capacity' is a potentially misleading long established term because heat capacity evokes the idea of heat contained fluid-like in a material. Warren advocates replacing the term 'capacity' with the more appropriate word 'acceptance' because the false implication of heat storage is negated.

Quilez-Pardo and Solaz-Portoles (1995) claim that teachers' conceptions might influence the problem-solving strategies of the learner from their chemical equilibrium studies, and included the connection to heat. The term *heat energy*, regardless of its source and application, is much broader in context than scientists and science educators think (Pushkin, 1997). Pushkin believes that scientific terminology can, and should, be better defined by all fields connected to science education, regardless of professional paradigm or personal epistemology. Educators cannot universally agree on these terms. The definition of heat is troublesome especially with regard to the first law of thermodynamics. Heat might best be described as a transfer, or flow, of thermal energy from something hot to something cold; it is a process; not an entity. Pushkin contends that it is much better to introduce students to knowledge for analysis and application rather than dictating information such as definitions for use.

Slisko and Dykstra (1997) state that energy is the capacity to do work and mechanical work is done when a force moves an object through a measured distance. This emphasizes again that work is a process to be expressed utilizing verbs. Energy can exist in different forms, but not all forms are usable. Thomas and Schwenz (1998) conducted a physical chemistry study which discusses how instructors might overestimate students' abilities in a particular advanced course. The researchers suggest that instructors need to elicit qualitative descriptions and explanations for what is happening in a particular chemical system where heat changes are significant. Through the process of probing fundamental thermodynamic concepts teachers may address and remediate students' alternate conceptions.

Sozbilir (2003) reviewed specific literature regarding the alternate conceptions of heat and temperature. The work included a tabulated summary of those conceptions and a discussion on meaning derived from the terminology in use. He noted that different explanations for a term may cause confusion in understanding the concept; heat may be used in conjunction with other terms which provide another source of difficulty. There are a variety of definitions for the concept, varying from scientists' to publishers' to instructors' and to students' viewpoints. Sozbilir contends that the best documented areas in science education are students' ideas, and misconceptions, of heat and temperature as these terms are familiar words from daily life. Students' understanding of these concepts are key to understanding many other scientific concepts, with studies showing that even adolescents and scientists have similar misconceptions. The researcher believes that the foundational principles of heat and temperature are shaky; their examination of science instructors and students revealed a lack of knowledge concerning thermal equilibirium, specific heat, and heat capacity. The main confusion seemed to come from the meaning of thermal equilibrium, the physical basis for heat transfer and temperature change, and the relationship between specific heat, heat capacity, and temperature change.

Brookes, Horton, Van Heuvelen, and Ektina (2004) examined communication in physics linguistically. They presented evidence, in the context of the concept of heat, that physicists speak and write about physical systems with sets of systematic metaphors that are well understood in their community. However, many students appear to misinterpret and overextend these same metaphors producing alternative cognitive conceptions. For example, the researchers attempted to explain why students might view heat as a state-function because they see a system as a container of heat. A state-function, or thermodynamic potential, is considered any property of a system that depends only on the current state of the system, not on the process of obtaining that state. Temperature and pressure are examples of state-functions. This study showed that the language used by physicists did not reflect the scientific understanding of heat defined as a process, not a substance. Significantly, Slisko and Dykstra (1997) state that there is no definition of what heat is that all scientists agree upon. For instance, some scientists view heat as a process of energy transfer while other scientists talk about heat as a substance or form of energy.

(ii) Historical Development

There is a tradition, not normally reflected in textbooks, that the nature of heat as a topic should be taught historically with the use of examples to illustrate the gradual development of modern ideas. Harrison and Treagust (2002) claim that students need to understand the key aspects of the historical process if they are to change their intuitive views about science concepts. Cotignola, Bordogna, Punte, and Cappannini (2002) surveyed and summarized the historical development of the heat concept. They began with Aristotle's cosmology which included the concept of fire as one of the four basic elements of nature, and progressed to the Greek caloric concept of heat as 'a subtle imponderable fluid'. From this period they detailed scientific thought and debate through the 17th and 18th centuries highlighting that the caloric theory was questioned by Rumford's cannon-boring experiments in 1798. The wave theory of light and the success of the kinetic theory followed. The authors carefully described the appearance and evolution of the energy concept through the 19th century to finally emphasize the development of the first law of thermodynamics often termed the law of conservation of energy. The researchers' study illustrated that some ideas for the caloric model are found to be reinforced by magnitude names and unit definitions emanating during the early stages of thermodynamics development, and showed how the energy concept transformed our understanding of heat and temperature.

Brookes (2006), in his thesis, outlines the historical development of the heat concept as well. He too talks about the caloric theory developed by Black and Lavoisier, and Rumford's challenge to this theory. Significantly, in his treatment, Brookes details the manner in which scientists' ideas are in flux. Historically, scientists talk about heat as a substance at first, then as a process, and back to a substance again. I agree with Brookes in that educators were likely trying to find a way of productive reasoning about the heat concept aside from maintaining the correct definition. I suggest that this type of reasoning is still happening in the modern classroom with instructors today.

With regard to units of measure, Chang (2004) explored the invention and development of the thermometer. This invention led to more precise definitions of heat, temperature, and thermal equilibrium. Chang, for instance, described in detail the problems encountered with determining the fixed boiling and freezing points of water. I contend that an historical approach aids the student in concept development and the need for clear terminology.

De Berg (2008) argues that the examination of historical case studies of scientific concepts is a useful medium for showing how scientific ideas originate and change over time. This is but one means of helping students conceptualize ideas. He presents an historical discussion of the caloric theory of heat, the development of the thermometer, and temperature, including specific examples from the'Harvard Case Studies' publications to illustrate the growth of the heat concept. The author also conducted a case study using first-year university chemistry students. De Berg confirms that misconceptions, such as the error in using heat and temperature synonymously, are a hindrance to student learning. This I also find valid. Studies in the history and philosophy of science have shown how important misconceptions have been as 'stepping stones' in the development of scientific ideas or not. New understandings have to be built. De Berg argues the need to treat the heat/temperature topic from an historical-philosophical perspective as having the advantage of informing the student about the nature of science in a highly contextualized, content-laden framework. De Berg states it is helpful to develop students' conceptual development using actual historic experiments in the laboratory. But, he does acknowledge it is difficult for teachers to find accurate historical accountings of scientific concepts that are useful for classroom use. He suggests that based on his work the utilization of historical case studies are both worthwhile and successful in the development of appropriate concepts of heat and temperature. However, this endeavour requires the use of some historical episodes students can identify with, and therefore be introduced to, the nature of science, that the information can be divided into small increments, and that students make use of a classroom textbook. Chiu (2003a) suggests utilizing scientific historical cases so that teachers might treat analogies as theory developers, conceptual change facilitators, or invention catalysts. Quilez (2007) outlines four main points for the utilization of history in improving chemistry classes: historical research on the development of chemistry gives explanatory clues about the processes giving rise to chemical concepts, historical knowledge helps in understanding students' alternative conceptions, the history of chemistry teaches students about the nature of the discipline, and the use of history aids teachers in formulating chemical problems and designing effective learning sequences. Quilez also gives teachers suggestions on how to translate his findings into classroom practice. As with De Berg (2008), Quilez suggests using the laboratory to replicate 19th century experiments. Justi and Gilbert (2002) add enhancing students' capacities for critical thinking to the list. I think if students see historical alternate conceptions as part of the process in the evolution of currently used scientific concepts they might better appreciate the value of a scientific method. Historical studies have shown how alternate conceptions have been used as scaffolding to produce modern-day accepted scientific ideas (De Berg, 2006). Students, given examples from these historical studies, might identify alternate conceptions and build new understandings – closer to the accepted scientific ones.

(iii) Towards Conceptual Change

Taber (2001a) argues that conceptual development may be described as a gradual shift from the learner's preferred choice to another alternative explanation. Harrison, Grayson, and Treagust (1999) conducted a case study focusing on one Grade 11 student's cognitive and affective changes that occurred during instruction on the topic of heat and temperature. The researchers suggest these terms are often poorly differentiated in science because they are frequently confused with internal energy. The instructional study used an inquiry approach coupled with concept substitution strategies aimed at restructuring previously identified alternative conceptions. The findings of Harrison et al. (1999) indicate that at the end of the unit of study the subject held less highly intuitive conceptions of heat and temperature and that the participant experienced a form of conceptual change, specifically, the status of the scientific conceptions increased at the expense of his intuitive conceptions. However, the study does not clearly explain the exact nature of the subject's conceptual restructuring. The researchers claim the participant's conceptual change was non-revolutionary and cumulatively piecemeal but perhaps the conceptual change experienced was more, in part, the product of gradual concept exchange processes.

Taber (2000b) asserts that there is a need to reinterpret curriculum for students. We, as instructors, must provide the level of complication that is appropriate for subject and learners. While simplification is often necessary, a point will be reached where the logical structure of the subject is compromised. One difficulty in this thinking pertains to the problem of a definition. Taber provided one example in research where oversimplification yielded the flaw that if the term heat flow is taken to mean the process by which energy transfers as a result of temperature difference, and heat means the energy transferred in the process then students might think that internal energy and heat are the same. I concur with Taber in the belief that it is the essential part of the instructor's craft to determine acceptable and appropriate simplification for a particular group of students.

Goedhart and Kaper (2002) explore the wide gap between the way the terms heat and energy are used in initial chemistry education and the way these concepts are used in thermodynamics. The researchers elaborated on the difficulties teachers have with trying to make students see the usefulness of the two distinct terms and their relationship by way of heat capacity. They believe the problem lies with students having only a vague understanding of these words. Jasien and Oberem (2002) contend that it is generally assumed students have a firm grasp of elementary ideas of thermal equilibrium and heat transfer because it is assumed these ideas become more firmly rooted in the students' content knowledge the more they are exposed to them. Some of the heat ideas are prerequisites for understanding the more complex concepts related to thermodynamics. The researchers point to a general misunderstanding of ideas related to thermal equilibrium, heat capacity, and specific heat. Possible solutions such as class discussion and an inquiry-oriented approach are suggested. In addition, Laburu and Niaz (2002) initiated a study based on thirty-two ninth-grade students in a public school in Brazil. Their results broadly supported the claim that the differentiation between heat energy and temperature constitutes considerable difficulty for students. They concluded that discussion, reflection, and consideration of alternate and conflicting situations allow students to construct models which progressively increase heuristic and explanatory power. Classroom interactions, within an epistemological perspective, play a crucial role. My epistemological perspective draws from a context-based approach in that 'personal relevance' is a key determiner of what interests students and teachers in chemistry education. Students like to relate chemical principles to everyday life. I agree with Laburu and Niaz in that students, teachers, and scientists all build models in different ways. Possibly it is the classroom interactions, within a particular epistemolgical context, that cause constructed student models to change. Students, instructors, and scientists construct knowledge to fit from very different experiences. Toward this endeavour I suggest a relevant analysis of textbooks would be both helpful and essential in clarifying meaning and expression of the heat concept as textbooks are a rich source of instructional material.

2.5. Textbook Analysis

(i) The Terminology – Language and Definition

The focus of this study is an analysis of the language of the textbook in search of alternate conceptions. In science textbooks, scientific writing, scientific discourse, and everyday experience, scientific terminology is used in a broader and richer range of ways with little agreement about what constitutes the appropriate usage of scientific terms**.** Traditional courses are centered on the textbook as the source of knowledge with historical examples being used to illustrate the gradual development of modern ideas in science.

Zemansky (1970) recorded, from his teaching experience spanning the years from 1925 to 1966, that he was struck by the confusion in learners' minds whose main source of information consisted of material gleaned from elementary physics and chemistry textbooks. The mix-up between the words temperature and heat were evident. He uncovered errors such as the reference to the 'heat in a body', a simplification that is not possible; using heat as a verb, such as 'heating' something; and combining heat and internal energy into one undefined thermal energy concept, meaning heat is discussed on one page and energy on the next page of the book. These are good examples of the multilayered semantics associated with heat. Warren (1972) confirmed that in many texts heat is explicitly or implicitly defined as if it were internal energy. He also noted that problems arise when there is an attempt to contrast heat with temperature.

Tripp (1976) acknowledges that the concept of heat is basic to an understanding of energy transfer and elementary thermodynamics. The generally accepted qualitative definition of heat is heat is transferred from one system to another solely by virtue of a difference in temperature. His study included consultation with many chemistry textbooks where he specified that the concept of heat was presented either incorrectly or superficially. According to Tripp, the concept is problematic due to poor textual treatments, qualitative versus quantitative measurement and descriptive differences, unit and measurement devices (for example, calorimeter calibration choices, comparison of a wet and dry calorie), the difference between heat and temperature, improper interpretation of historical experiments, and language use. Often there tends to be a correlation by students and text authors between the words heating and heat. Tripp also recorded that the term heat capacity is a source of semantic confusion.

Slisko and Dykstra (1997) raised the broader issue of the nature of scientific terms and their role in instruction. Using specific examples of energy flow and electricity they postulate that when a chemistry text uses terms in inconsistent ways there is no logical method of sorting out the meanings of the terms. Hence, if standard interpretations of scientific knowledge to be taught do not actually exist, then how can the standard interpretations of scientific knowledge be established as goals to be accomplished? Slisko and Dykstra further maintain that there is no agreement as to the meaning of the terms among scientists and texts. There is little agreement concerning what constitutes the appropriate usage of scientific terms suggesting terminological diversity. Established practice proves that erroneous, misleading, and conflicting conceptualizations, either in different textbooks or within a single text, hardly contribute to better teaching and learning. Precision is not enough; implied agreement in the physics community is necessary. Slisko an Dykstra (1997) argue that teachers need to make an effort to help students reexamine their initial knowledge coloured with many alternate conceptions, as well to build new knowledge consistent with their new experiences with natural phenomena. Meaning occurs by sharing terms with each other through interaction with each other. Conflicting conceptualizations plus confusing linguistic and logical structures arise in the network of related terms. Therefore, I argue definitions have sense only in rich contexts consisting of practical activities and sensible questions supported by different representational means.

(ii) Ontology and Coding

Brookes, Horton, Van Heuvelen, and Ektina (2004) analyzed physicists' discourse and provide evidence suggesting a connection between the misinterpretation of language read and heard with students' alternate conceptions. They developed a scheme to code language used to describe physics ideas, and they used this coding scheme to analyze textbook language about heat in trying to connect this language to students' reasoning about heat in thermodynamics systems. Thirty-two calculus-based introductory university physics students were sampled. The authors contend that language is not just a passive representation of reality but also influences what the language user perceives and understands. They hypothesize that students' confusion with work and heat may have linguistic origins. The authors attempted to resolve the issue by considering language to be a representation of a physicist's model in the same way as a picture or an equation. In a basic thermodynamic model the objects are considered point particles, the processes are heat and work or energy transfers, and the system possesses states, such as temperature and pressure. Encoding this ontology can be seen by comparing the phrases 'heat (a substance) flows' to 'energy is added (a process) to the system by heating'. The grammar of the phrases uncovers the implicit ontology. The researchers analyzed three popular college-level introductory physics textbooks arguing that such textbooks represent a higher standard of linguistic rigor than the regular talk of a physicist, therefore a study of textbooks gives us an upper level on the quality of language used to refer to the concept of heat. The goal of the analysis was to provide a scheme to help understand the types of meanings which might be construed from the language of physics. Results showed that from six definitions of heat extracted from the textbooks, four were substance-based (using nouns), and two were process definitions (involving more verbs). The authors identified a scheme consisting of six metaphorical classifications of heat, for example, 'heat is a substance' or 'heat is a process', and calculated by percentage how often the clauses appeared in a particular textbook. The researchers concluded that although physicists know that heat should be thought of as a process, the coding from the study reveals that the language used did not reflect this understanding.

The thermal study of De Berg (2008) included a general chemistry textbook analysis of heat. Ten first-year university textbooks were analyzed for illustrations or models explaining the difference between heat and temperature. The researcher's text analysis revealed the emergence of three different concepts for the definition of heat. I agree with De Berg on the matter of multiple definitions presenting a confusing picture for students. Identified problems included the concepts of hotness versus coldness, the property that determines the direction of heat flow, and the measurement of average kinetic energy of different particles within a substance detailing the process of energy transfer. The study concludes that students need to be provided with the necessary intellectual tools for a critical reading of textbook treatments regarding the concept.

Doige and Day (2010), through an analysis of several science textbooks, explore the conceptions of heat with a focus on the definition of heat. Their study shows a great variation in a given textual definition both within and between science disciplines. As well, Galili and Lehavi (2006) reported in a study that instructors do rely on textbooks for knowledge but acknowledge that the textbook definitions given were not explicit enough or scientifically valid. In addition, Day, Doige, and Young (2010) conducted a textbook study on the heat concept specifically within the discipline of physical geography. Their analysis revealed that many modern introductory physical geography textbooks reflected a usage of heat that was provided and apparent in physics and chemistry texts prior to the late 1960s. I concur with the researchers when they maintain that the difference between everyday and scientific vocabulary used by instructors must be made clear and distinct so students are not confused.

(iii) Conceptual Change

Baser and Geban (2007) argue that a conceptual change oriented instructional method produces significantly greater achievement in understanding the concept of heat. They talk about the text as a tool which enables students to construct meaning, and for this reason textual language requires careful reading and comprehension. However, it is worthy of attention that the students utilizing a conceptual change approach still may not have an excellent understanding of the science concepts after instruction. Therefore, the process needs improvement in effecting conceptual change from existing alternative conceptions to acceptable scientific conceptions.

2.6. Animations and Graphical Representations

Learning is an active process by which an individual constructs meaning from experience and events by integrating them into existing conceptual frameworks. All learners do not hold or construct mental models in the same way. Williamson (2008) provides a number of representative studies suggesting that students' understanding of chemistry, for instance, the particulate nature of matter, can be enhanced by using physical models, student drawings, computer programs that generate molecules, and student-generated drawings or animations. The criteria for success included improved test scores for conceptual questions, better student-created representations of chemical phenomena at the particulate level, and more accurate student predictions of experimental outcomes on the macroscopic level. Further, there is consensus in the literature that more than one visualization technique should be used to help students create mental images of chemical concepts.

An animation is a changing graphic display. Although there are numerous ways graphic displays can change, the typical animation changes continuously in time and shows the operation of a system from start to finish, at the same temporal and spatial grain, and from the same temporal, spatial, and conceptual perspective. In general, animations use primarily structural graphic information without enhancing or highlighting that information (Tversky, Heiser, Mackenzie, Lozano, and Morrison, 2008).

Expertly devised animations may be effective for understanding science concepts. Graphics can facilitate comprehension, learning, memory, and communication. Studies report one such workshop involving chemists, chemical educators, and software developers who worked through complex ideas such as determining the role of particulate animations in the classroom, and detailing the characteristics of a good animation (Jose & Williamson, 2005). Most chemistry textbook ancillaries now include clips of animations depicting particle behavior as well as incorporating particulate drawings in the textbooks. Many of these also include multiple representations for the macroscopic, particulate, and symbolic dimensions. The representational and computational capabilities of computers can be used in designing multiple and co-ordinated representations. The use of such computerized models has been advocated as a way to improve students' understanding of scientific phenomena. Moreover, studies of students' and experts' use of chemical computer-based models have shown they can also improve visualization in chemistry (Justi & Gilbert, 2002).

I think that animations are often viewed as more realistic with the presumption being that instructional resources seeming closer to life are better. I find that visualizations, including animations, are not always a benefit. Just as for language, there are no quality gradations. Like metaphors, animations can mislead and create misunderstandings (Kaiser, Proffitt, Whelan, & Hecht, 1992; Wieman & Perkins, 2006). Science educators worry that students might take visualizations too literally; especially abstract ones, such as movements of molecules and particles. The bias to improve causality, agency, and intention to motion of abstract figures can yield misinterpretations. For example, if students watch types of molecules moving as coloured balls tumbling, hitting each other, sticking together, or coming apart they may interpret an 'intent' of hiding, pushing, or chasing into the animated conceptualization of molecular bonding (Tversky, Heiser, Mackenzie, Lozano, & Morrison, 2008). I think a chemistry animation often mistakenly portrays atoms or molecules 'wanting' or 'needing' to do something in the pursuit of stability.

Wieman and Perkins (2006) believe that online interactive simulations (sims) may improve science education. Information technology potentially offers opportunities for improvement. Their research shows that this new medium and process effectively engages students. Ideas can be conveyed in powerful and different ways, used in a wide range of educational settings, and be language convertible. In their study Wieman and Perkins emphasized the connections between real-life phenomena and the underlying science. They suggest making the visual and conceptual models of expert scientists accessible to students and teachers. The researchers do note that a simulation *per se* does not automatically have, or readily come with, great pedagogical power. It is essential that a development process involving multiple cycles of careful testing be employed - often a costly venture.

Animations of particle behavior, such as Greenbowe's (2005) retinue of resources: http://www.chemiastate/edu/group/Greenbowe/sections/projectfolder/animastionsindex.html, are available on the Internet. This site provides a vast array of on-line computer simulations and graphical representations of lesson plans. The study of heat transformations is a primary unit. Other examples of animations include: Regional Math and Science Centre Resources – Using Chemistry Knowledge (HS) with teaching units and lesson plans [http://svsu.edu/mathsci-centre/uploads/science/gsHcsk.htm.], and Outstanding Chem Com Teacher's Resource Centre, where the chemistry presented to the students builds upon vocabulary, thinking skills, problem solving, and lab techniques for traditional chemistry courses. Finkelstein, Adams, Keller, Perkins, and Wieman (2006) produced a new suite of computer simulations, from the Physics Education (Phet) project [http://phet.colardo.edu/teacher_ideas/view-contribution.php?contribution_id = 410 & refer…], identifying features of these educational tools and demonstrating their utility in a broad range of environments. This site includes simulations which have been researched and tested, and contain the topics of heat and thermochemistry. These simulations follow a constructivist approach. Scholastic Research and Results (2007) uses an animated story to reveal scientific misconceptions to students. Through a mix of visuals, print materials, and hands-on activities students are able to invalidate an incorrect notion and come to understand the correct scientific concept. An interactive word wall reinforces and extends content-rich vocabulary. All these resources are of tremendous value to instructors and researchers.

2.7. Implications for Instructional Practice

The key educational outcomes from my literature review include:

1. Students create meaning from personal world experiences and previous instruction. Concept development occurs when these meanings are linked together to form sets of understandings. Good science instructors try to promote meaningful learning in their students.
2. Constructivism is a heterogeneous movement consisting of many facets. It emphasizes learning beyond plain knowledge absorption. However, although used in science instruction, there is no single, coherent, or theoretically consistent orientation.
3. Alternate conceptions in science are diverse, deeply rooted, tenacious, and with hidden origins. For these reasons they need to be identified so they can be understood in the pursuit of meaningful learning.
4. Alternate conceptions often occur with the study of heat and temperature. It would help alleviate the problem if instructors speak about heat as a process, not as a substance or form of energy.
5. Historical studies detailing the development of the heat concept may offer assistance in the understanding and eradication of alternate conceptions.
6. Textbook analyses reveal many linguistic difficulties and graphical misrepresentations relative to thermal alternate conceptions.

7. Most importantly, in my view, utilizing practical constructivism provides one way of replacing alternate conceptions with more scientifically acceptable concepts.

Good instructors try to find new strategies for instruction and evaluation; animations, graphical representations, models, critical discourse, hands-on activities, and improved curriculum design will aid in improved conceptual development.

(i) Finding and Identifying Alternate Conceptions

From this review there are numerous implications for instructional practice. Achieving good, chemically and physically accurate, understandings of the concepts comprising science presents instructors with a significant challenge. Science will remain a mystery for many people if this is not taken seriously. Bucat (2004) declares that, as a result of research into students' understandings, we have lists of student alternate conceptions, often accompanied by blind statements about prevention or curative actions. As chemistry instructors we have an enhanced knowledge of the conditions for effective learning, but little guidance as to how this knowledge might be applied to the teaching of particular topics. It is important for science educators to understand students' knowledge of the heat concept and to develop new curricula and teaching methods for science classes; conceptual change research should be more than just simply altering a particular belief.

(ii) Instructor Education Improvement

The purpose for identifying, cataloging, and studying alternative conceptions in science would lend itself to new and improved curriculum design, teaching strategies, test and concept evaluation instrumentation, instructor management of student discourse, listening-discussion stimuli for modeling, and the establishment of a broad bibliography for future research needs. Mulford and Robinson (2002) clearly state that knowing the nature and extent of students' alternate conceptions is, by itself, not enough to improve the effectiveness of instruction. Students extend and modify their knowledge by comparing it and integrating it with new stimuli. Checking how our knowledge works is key to checking its validity. But if we are never in a situation where our knowledge fails us we have no need to revise it. Thus, in order to change their alternate conceptions students, and presumably instructors, need to be exposed to discrepant events, that is, situations where their incorrect knowledge does not work. I suggest that once instructors identify meaningful alternate conceptions they can attempt to share with their students more relevant and alternative scientifically accepted meanings to facilitate the unlearning or eradication of any misconceptions.

Misconceptions must be identified and unlearned to facilitate meaningful learning. Taber (2002) contends that less talented teachers operate with an impoverished theoretical underpinning for their practice. For example, many instructors demonstrate the caloric viewpoint with the language they use when teaching about heat (Veiga, Duarte, & Maskill, 1989). Students bring ideas from real life to knowledge and make inferences from linguistic and other cues interfering with learning chemistry. Many alternate conceptions may be generated by students as they grapple with information and models, presented in school, which they are unprepared to imagine or understand (Kind, 2004). Being informed about research findings can help a teacher prepare and plan more effectively; cues can lead to alternative conception identification and provide conceptual expansion strategies. As a remedy to this situation, Tan, Taber, Goh, and Chia (2005) suggest instructors rephrase a point in more technical language, rather than using too simplistic a vocabulary.

There is a definite need for instructors and researchers to collaborate with the goal of developing alternate strategies which can be employed to help students overcome faulty alternative concepts. Canpolat, Pinarbasi, Bayrakceken, and Geban (2006) investigate the effect of a conceptual change approach over 'traditional' instruction (teacher provided instruction through lecture, discussion, and utilized textbooks) on students' understanding of a fundamentally important chemical concept equilibrium within an introductory university chemistry course. The conceptual change approach was applied in the experimental group whereas traditional instruction was followed in the control group. The researchers wished to identify student held alternate conceptions about this topic and evaluate whether process skills and treatment explain a significant portion of variance in the understanding of equilibrium. Using analysis of covariance the findings of the study indicate that instruction based on conceptual change texts accompanied by models and demonstrations was more effective than traditionally designed instruction. A conceptual change text introduces a common theory, belief or idea, refutes it, and offers an alternative theory, belief, or idea that is shown to be more satisfactory.

I suggest instructors employ Toulmin's model of argumentation in chemistry classes as a useful process to clarify concepts. Toulmin's model of argument details how conclusions are reached through logical reasoning. Zarebski (2009) describes Toulmin's view as meaning traditional and formal logic cannot be ascribed to discovery and scientific arguments, implying no formal constructions do justice to the practice of scientific inferring, as there is always a large gap between any formal procedure and its practical application. Zarebski lists six elements of Toulmin's consideration of a persuasive argument. These elements encompass an interconnected set of a claim, data or grounds that support the claim, warrants that provide a link between the data and the claim, backings that strengthen the warrants, qualifiers that indicate the strength of leap from data to warrants, and finally, rebuttals which point to the circumstances under which the claim would not hold true. Toulmin is convinced that scientific practice cannot be properly understood solely in terms of formal methods because many formal methods have limited applicability. Zarebski considers that Toulmin's ideas about scientific discoveries have some explicatory value as they contribute to the way we understand science, its discoveries and arguments. For example, Toulmin suggests using free professionally trained imagination to reach beyond present practice. I consider Toulmin's idea of the coming to particular findings in science through exchange of reasonings and findings as largely the result of consensus acquired with the scientific community, not the mere principles of logic, significant to my research study. Toulmin advocates that logic should not be a universal pattern of rationality. Science frequently might use informal modes of reasonings to come to a conclusion. I suggest argumentation has the power to play a central role in the building of explanations, models, and theories as scientists use arguments to relate the evidence they select to the claims they reach through the use of warrants and backings. Science learning should involve the construction and use of tools, such as argumentation, which are instrumental in the generation of knowledge about the natural world. However, careful attention needs to be paid to the contextualized use of language as to what constitutes a claim, piece of data, warrant, and backing.

(iii) Conceptual Change Education

Conceptual change and teaching for conceptual change are complex processes. Many educators advocate the use of historical narratives as one possible context for improving science education. A study by Metz, Klassen, McMillan, Clough, and Olson (2007) illustrates several ways to expand the view of telling narratives as conducive to integrating the history and nature of science with science teaching. The development of such historical narratives has the power to make science more meaningful and understandable in the classroom. Historical studies in chemistry may give explanatory clues about the processes involving the evolution of chemical concepts, such as heat for example.

Treagust and Duit (2008) argue that conceptual change perspectives still have the potential to significantly improve instructional practice. They further suggest that actual practice is far from what conceptual change perspectives propose considering the difficult and time consuming process of change. The researchers provide many examples of ontological conceptual changes, such as the development of heat from a flowing fluid to kinetic energy in transit. Treagust and Duit claim that desired changes to students' ontologies are not usually achieved in schools because many concepts are not presented by teachers or textbooks with any ontological differentiation, for instance between process and material. The analysis of textbooks is of pivotal importance because they are the most widely and frequently used teaching aids at all educational levels (Justi & Gilbert, 2002). I suggest this will not always be the case considering the advancing technological world we live in. Chiu (2003b) recommends that book publishers accompany chemistry concepts with multiple, appropriate, and accurate illustrations and graphs. Curriculum developers should also provide correct and suitable explanations for the concepts as scaffolding for students' learning in chemistry.

I would like my students to be able, and willing, to practically grasp the scientific way of knowing the world. I think that in talking about students' conceptual change, instructors should try and investigate the concepts from the student's point of view. When considering conceptual change instructors must look beyond examining only rational and practical considerations to a wider range of student motives, interests, and goals. Gilbert and Watts (1983) contend that the more closely any study approaches an actional view of a concept the more likely it is to contribute to conceptual development. The acceptance of existence, user value of alternative frameworks, and framework expansion of applicability bring modification towards a consensus view of formal science.

My review of the literature shows that although a considerable amount of research has been done with respect to the heat concept, not much attention has been devoted to providing a plausible framework for differentiation and understanding between thermal terms. More work remains to be done in reviewing the literature to have an impact on science teaching, especially with regard to the alternate conceptions instructors may bring to the classroom. I argue that instructors need to engage in critically reflective discourse, both verbal and written, to determine students' and their own conceptions of the meaning of the heat term with specific reference to the ways in which the concept is taught in science.

Chapter 3: The Methodology and Method

3.1. Prologue

In this chapter I elaborate on the problem that initiated this study; I provide an explanation of the qualitative methodology employed; a description of the method utilized including the design of the study, ethical approval confirmation, participant recruitment and selection, the survey-questionnaire instrument format, data collection and analysis techniques; study assumptions and limitations; and I give a brief discussion and conclusion. The method details the specific systematic procedures of the study; the methodology defines the principles determining how such procedural tools are deployed and interpreted.

The purpose of this study is to determine the conceptions and alternate conceptions of instructors teaching the ‘heat’ concept as taught in several representative chemistry classes in British Columbia colleges and universities. To support my study I also offer a textbook analysis of the linguistic use of the terms ‘heat’ and ‘temperature’ in selected chemistry textbooks used by these instructors for the same purpose. The main goal of my study is to ascertain the nature and extent of chemistry instructors’ knowledge about the heat concept by identifying the relevant conceptions he or she holds. My research aim is to develop theory and explain processes constructively. It is my hope this will provide insight into conceptual change processes.

3.2. The Problem

Research has shown that chemistry students have many alternate conceptions about the heat concept (Slisko & Dykstra, 1997; Sozbilir (2003), Brookes, Horton, Van Heuvelen, & Ektina, 2004; Brookes, 2006). Based on my own teaching experience and a review of the literature I am both interested in, and concerned about, chemistry instructors being a source of these alternate conceptions. I find it problematic that thermal alternate conceptions may be passed on to students during the instructional process.

3.3. The Methodology: Definition and Description of Grounded Theory

Grounded theory is a qualitative approach in which an individually derived theory about a phenomenon is grounded in the data in a particular context. I contend that grounded theory is a powerful way of gaining relevant data in concept building. This methodology has the potential to clearly show how scientific ideas diverge in directions along different pathways possibly giving way to the formation of alternate conceptions. My rationale for choosing grounded theory as my methodology emanates from thinking that it is possible to theorize from qualitative data grounded in the lived experiences of people. I have come to think of the process as ‘cleaning your mind’ or ‘washing any academic sludge out of the mind’ so as to reduce any preconceived notion before starting a learning course.

What is grounded theory? Brookes (2006) endeavors to explain grounded theory by comparing it to a ‘grand theory’. Grounded theory was introduced because the sphere of human interactions is too large to study and too complex for a few grand theories to attempt to explain everything. The term 'grounded' refers to the idea that a grounded theory should be based on data and not on intuitive speculation. A grounded theory explains a particular smaller subset of the given phenomena with no attempt to explain all acquired data. Grounded theory specifies a set of guidelines and concurrent directions, not a specific recipe or set of techniques, in which research may progress over time:

1. The primary goal is to develop a substantive grounded theory. Substantive means real or related to a specific situation, therefore the research begins with a specific location or condition.
2. Comparative analysis occurs next. This process involves note-taking, memo-writing, and coding. Relevant categories are defined with their specific properties, and named.
3. Theoretical saturation occurs when all categories and their properties are identified.
4. Literature, having the same status as data, enters only after the first attempt at substantive grounded theory occurs. The literature is emergent.
5. The grounded theory is a process of refinement and growth of any formal theory, and continues for as long as the theory is seen as relevant and usefully applicable.

Grounded theory, as articulated by Glaser and Strauss (1967), means generating theory from open-ended qualitative data of a sociological framework thereby complementing theory verification. They argue that the legitimacy of knowledge is grounded in the idiosyncracies of lived experience. Instead of testing preconceived hypotheses using existing literature, researchers employing grounded theory techniques constantly look for new perspectives that might help them develop their grounded theory. Wimpenny and Gass (2000) further explain that grounded theory is not a specific method or technique but rather a style of doing qualitative analysis which emphasizes the discovery of theory from collected data. Grounded theory, through a process of constant comparison and reduction, aims to establish tight, well-integrated theory built from well-defined concepts arising directly from empirical research. The position is to begin with an area of inquiry and allow whatever is theoretically relevant to emerge (Strauss & Corbin, 1990). Research to generate grounded theory deliberately avoids tightly defining the study focus, instead the researcher begins with a problem or area of interest (Taber, 2000a) so as to take account of any questions arising.

Kennedy and Lingard (2006) discuss how grounded theory initially was suggested in response to positivism. Positivism is a dominant scientific or experimental research paradigm for philosophers thinking about science. Positivism is defined as the search for one grasped truth to generate knowledge. It is characterized by recognizing only positive and definitive facts about observable phenomena, the reliance on the researcher being detached and objective, and the rigorous attention to valid and reliable data. Positivism claims the existence of one single reality and one absolute truth. Charmaz (2000) contends that the power of grounded theory lies in its tools for understanding empirical reality; these tools are reclaimed from their positivistic underpinnings by stressing emergent and constructivist elements. Grounded theory is a research methodology designed to develop, primarily through qualitative data collection and analysis, a well-integrated set of concepts providing a theoretical explanation of a social phenomenon. Grounded theory is a systematic and scientific procedure for generating knowledge from qualitative data but it is also an interpretative inquiry process as well. I am interested in distinguishing between ‘what we take to be true’ (epistemology), from ‘what we take to be real’ (ontology), from ‘what we take to be of value’ (axiology) in the classroom.

Seaman (2008) describes through a literature review how grounded theory’s stance toward inquiry has evolved from objectivism to constructivism. Constructing grounded theory is now a process more of careful interpretation rather than of discovery. The traditional rules of grounded theory meant waiting for a theme to emerge from the collected data. Constructivists have transformed grounded theory from a strict methodology into a flexible approach. Seaman explains that recent constructivist and postmodern insights are challenging long-standing assumptions, most notably suggesting that grounded theory can be flexibly integrated within existing theories.

According to Charmaz (1995, 2000), the five principles of the new progressive development of grounded theory are: (i) the structuring of inquiry, (ii) the simultaneity of data collection and analysis, (iii) the generation of new theory and not the verification of existing theories or hypotheses, (iv) the refinement and exhaustion of conceptual categories through theoretical sampling, and (v) the direction to more abstract analytic levels. Charmaz believes that grounded theory can bridge traditional positivistic methods with more interpretative methods. She offers a basic constructivist version of grounded theory emphasizing action and process, as well as meaning and emergence, within symbolic interaction complementing grounded theory.

There are many benefits to a grounded theory approach in an educational study. Open-endedness and flexibility are considered strengths (Charmaz, 1990), while the main benefit of using grounded theory according to Smith-Sebasto and Walker (2005) is that the emergent theory is related to the perceived reality of the participants. Grounded theory has the potential to offer rich narratives (full of detailed and descriptive data), value investigators’ and participants’ accounts as reliable, immerse the researcher in the data relying on the researcher’s interpretation, show that multiple data-gathering methods allow for formation and internal verification of complex theory, and illustrate constructivist ways of building theory.

3.4. The Method

(i) Design of the Study

My research study entails determining instructors’ various understandings of the meaning of the ‘heat’ concept as taught in college preparation and first-year level chemistry classes. I obtained ethical approval for this study from the UBC Okanagan Research Behavioural Ethics Board and the RISe Team. I randomly selected nine colleges and universities from the province of British Columbia and the Yukon for gaining access for participants. A science faculty member of each institution identified for me the names of currently employed and practicing chemistry instructors at their institution. For purposes of recruitment I contacted all chemistry instructors teaching college preparation and first-year levels from the randomly selected institutions for voluntary participation. I selected these instructors because they provide a sample of currently practicing chemistry instructors in the province and nearby Yukon and also due to their ready accessibility to myself the researcher. Initially I contacted prospective subjects by letter to invite participation. Nine instructors from three institutions responded to my invitation and indicated their desire to participate in this study. I then mailed the nine participants a specific formal letter of intent, including an enclosed consent form for signature, describing the research proposal in detail (Appendix A, p.78). I informed instructors that confidentiality and anonymity was ensured as no actual names of instructors or institutions are or will be identified in this study. I used numerical codes to specify data for future use. I made sure the participants were given the opportunity to obtain feedback throughout the course of this research study.

Step one of grounded theory involves the structuring of inquiry. To this end, developed from a table of specifications (Appendix B, p.81), I formulated a survey-questionnaire (Appendix C, p.82) to identify instructors' relevant inherent conceptions about the nature and extent of their knowledge about heat. I asked the participants to complete a survey-questionnaire style interview describing a lesson on how they teach the heat concept to their students within their own personal context, by making an audio or video digital recording of their responses to the survey (mandatory). I indicated writing down on paper their responses to the survey was optional. The time required for this process was approximately one hour. No students were permitted to be present during the preparation of the audio or video recordings. In order to elucidate instructors' treatment and understanding of heat in their respective classrooms, the survey-questionnaire included questions, diagrams for interpretation, and a description of resources used by the instructor. The results, after data analysis from the digital recordings, I present in Charts 1, 2, 3, and 4 (pp.59-61). The instrument I prepared also asked for demographic information, educational qualifications, and teaching experience. I tabulated the demographics of the participants in Chart 5 (p.62). The survey revealed that four of out nine instructors (about 44%) of the sample are chemistry majors and five out of nine (about 56%) are not (the majority biology majors). All but one of those instructors had no teacher training, unlike the college-preparation instructors who all had one year of teacher training. The survey-questionnaire was initially piloted and tested by two college-level chemistry instructors; no alterations or changes were requested.

I examined eight textbooks used by the participants in their respective chemistry classes for their definitions and explanations of heat and temperature, and analyzed the books for their use of illustrations and grammatical representations (Appendix D, p.86). I chose these criteria because they concern current understandings of heat and temperature with relevance to how these understandings are presented and built in a teaching-learning context. My textbook analysis looked at the language employed and the manner in which the heat concept is presented. I present the results in Tables 1, 2, 3, and 4 (pp.63-68).

(ii) Data Collection and Analysis

The second step in grounded theory methodology concerns the simultaneity of data collection and analysis. Once I collected all digital recordings and written responses from the participating chemistry instructors I examined the data for dominant and recurring themes. The central principle of data analysis in grounded theory research is the principle of constant comparison. Any interesting issues or incidents I noted in the data and compared against other examples to elucidate any differences or similarities. I continually refined the emerging theoretical constructs through comparisons with new examples from ongoing data collection thus producing a richness of information. At the beginning of the study I grouped incidents and issues into themes or categories named according to meaning. This process is called 'open coding'. I did not preset codes. I employed the constant comparison of themes to rename, reorganize, reclassify, or redefine thematic categories. 'Axial coding', a second level of coding, explores and defines the connections between the original categories. I utilized the process of memo-writing to formulate and develop any emerging theory at progressive levels of abstraction. Memos are written to define properties and characteristics of themes and categories, to elaborate processes and patterns identified within the categories, and to formulate emergent theoretical constructs (Kennedy & Lingard, 2006). The analysis process is complete when theoretical formulations produce an understanding or explanation of the phenomenon under study, in other words, a theory that, through the constant comparison process used in its development, is grounded in the data.

With regards to the process, I continually wrote memos and took notes throughout the process of data collection. The 'open' codes I produced from the data pertained to the language instructors used as words cueing specific metaphors, for example heat is a 'substance', or frames of reference, such as heat is 'fluid-like'. I established the codes as part of the metaphors instructors used in their definition, framing, and explanation of heat. The 'axial' codes I found apparent consisted of general reference examples used by instructors in their explanations of heat, for example referring to 'work' as being relevant (Chart 1, p.59), basic language ontological classification of heat into categories such as how many instructors define heat as 'nonliving matter' (Chart 2, p.59), and grammatical language classes, such as classifying heat as a 'noun' (Charts 3 and 4, pp.60-61). I collected different slices of data to provide, through the use of codes, a means of identifying similarities and differences. I clarified what fit, or did not fit, into various categories. The theoretical sampling allowed me the flexibility of following clues in the data, channeled and somewhat controlled, in the information previously collected and analyzed. I have included a glossary of terms for defining key vocabulary used in this thesis (p.x).

I surveyed the eight textbooks collected for analysis specifically for particular terminology and usage of the terms, 'heat' and 'temperature'. I paid careful attention to grammatical expression. The topics I compared and contrasted included the definitions given, any modeling or diagram inclusion, and any reference made to absolute zero (Table 1, pp.63-64). Once definitions were provided I established 'open' coding such as classifying textual definitions as heat being 'matter' or 'process' oriented

(Table 2, p.65). I did this in an effort to identify emergent themes. I then continued and determined the 'axial' codes with basic definitions being metaphorically classified by the use of heat clauses, such as 'heat is a substance that moves from container to container as it exits the system' (Table 3, pp.66-67). As a corollary to this work, I itemize in Table 4 (p.68) instructors' reflections and opinions on a textbook's effective presentation of heat, for example detailing what they consider to be poor examples of heat explanation. I gave the instructors the opportunity to provide suggestions for improvement to a textbook's treatment of the heat concept. I noted all of their suggestions.

(iii) Theory Generation and Refinement

The third step of grounded theory methodology involves the process of generating new theory, not the verification of existing theory, once all of the conceptual categories obtained through theoretical sampling have been exhausted. I reached a point in this study, after reviewing and examining the input from nine instructors, that there was no significant change to theory construction about heat occurring. After the fourth or refining stage, I was able to identify a 'model' of chemistry instructors' conceptualizations of heat which have features in common or in agreement. The construct blocks (Figures 1 and 2, p.69) illustrate the theories emerging in this study.

The fifth and final step in the process shows directing the theory to more abstract analytic levels. A theory by definition is never complete. Developing theory is an on-going process but after saturation I have written-up my results. This theory can then be further tested.

3.5. Assumptions of the Methodology and Limitations of the Study

There are some potential shortcomings or pitfalls identified with grounded theory research I had to consider. One pitfall may occur if the researcher applies predetermined themes rather than an emergent one. How does the researcher balance the search for emergent themes with the application of existing theoretical knowledge or concepts? This is a tension between emergence and the forcing of an idea (Kennedy & Lingard, 2006). Another pitfall might occur if, in the analysis procedure, the researcher generalizes too much describing themes instead of developing theory. The art of grounded theory is building the theory. Researchers engaged in grounded theory need to follow through and produce the theory. Possibly the evidence and interpretation may run together in accounts of grounded theory. I think this can be avoided by continually defining and redefining the data until theoretical saturation has been achieved. As well, Charmaz (1990, 1994) acknowledges that although there is criticism of grounded theorists for not showing enough concern for the accuracy of specific data, collecting data is considered very important in order to provide complete details of the processes and issues under study.

Thomas and James (2006) believe there is a central problem in the search for grounded theory. They suggest there is no free spirit existing in the researchers' minds which enables them to neutrally and inertly form some cognitive framework from the collected data. Theory cannot be drawn dispassionately from this data, this ground. I question if it is possible to totally cleanse, or clear, one's mind before beginning such an enterprise? To use grounded theory involves a rejection of basic understanding and entails an explicit denial of what we know and our ways as instructors of making sense. Thomas and James also argue that the starting points of qualitative inquiry are contradicted and undermined by the aims, claims, and methods of grounded theorists. The researchers reason that constructivist grounded theory may be detrimental to the best of qualitative inquiry; the procedures possibly yield less discovery and more invention. Even so, I am looking at the data with fresh new eyes.

Sample size is also an issue. This research study is qualitative in nature. Nine chemistry instructors participated in the study. They constitute a representative sample of practicing chemistry instructors teaching college preparation and first-year level chemistry courses in British Columbia colleges and universities. Although my study is unique and pertains specifically to a particular situation, I suggest it can be considered relevant because the acquired sample is representative of chemistry instructors teaching chemistry at this level. Other instructors may compare their situation to this one and find commonality using Toulmin's model of argumentation.

Eight textbooks were surveyed for their treatment of the heat concept. These textbooks were identified as the textbooks used by the participant instructors in their respective classrooms. Some instructors used the same textbook. Therefore I consider this textbook analysis both relevant and representative as it is linked with instructors' conceptualization processes. Other science education researchers, instructors and faculty members of secondary schools, colleges, and universities, as well as curriculum developers and textbook writers may read these same texts which means my data and analysis can be revisited over and over again.

3.6. Discussion and Summary

The results of my research study, that is the interaction between the data and the developing theory, yields emergent theories. This study on heat yielded theory of a basic conceptualization to new theory of a more complex and abstract nature In Chapter four, I illustrate a framework, through constructive blocks, interpreting the instructors' articulations of the heat concept. This is a visual representation of how all ideas fit together. Figure 1 (p.69) pictures the conceptualization of heat by the nine participating chemistry instructors; Figure 2 (p.69) characterizes the conceptualization of heat by the eight textbooks analyzed.

Grounded theory methodology allows a process to occur of moving from in-depth study of the specifics of nine individual cases to more general features of a wider context. I see it as an evolution and progression from personal conceptions to categories to general frameworks. There is a shift from the specific to the general due to the nature of the data collection and the analytical process. My research study permits the findings to be tested in the future through traditional deductive scientific methods with any identified alternate conception regarding the heat concept open to statistical testing.

Testing the generality of these findings from the instructors’ conceptual frameworks and how they evolve is more problematic (Taber, 2000a).

Chapter 4: The Results

4.1. Prologue

Traditionally, students' difficulties with the ideas of heat have been explained as students' having misconceptions, preconceptions, or alternate conceptions incompatible with scientifically accepted conceptions. Alternate conceptions can be very stubborn and resistant to change. It is therefore pedagogically important to be able to recognize and identify differing ideas and conceptions originating from different sources (Nakhleh, Lowrey, & Mitchell, 1996). As Brookes (2006) explains, human belief systems are naturally difficult to change because our beliefs are often strongly held and given up reluctantly. As intuitive beliefs may be grounded in physical experience, they are often intuitively obvious and therefore become a natural place for students and instructors to ground their thinking.

I have laid out my methodology for this research study in the previous chapter. In this chapter I show and describe, through the data collected and analyzed, specifically that:

1. Chemistry instructors do hold several alternate conceptions about the heat concept indicating that constructing scientifically accurate concepts in chemistry is not an easy task.
2. The use of grounded theory is a practical methodology to explain and develop instructors' ideas and provides a productive way to identify any alternate conceptions instructors might hold.
3. Chemistry instructors use linguistic representations, such as metaphor, to reason about heat. This language encodes the representations of a physical model which has an underlying ontology of matter, process, and state. The language chemistry instructors use to instruct the heat concept may be one way in which alternate conceptions are passed on to students or reinforced in students' minds.
4. Currently used chemistry textbooks use inaccurate language to discuss the heat concept. The language and diagrams contained in textbooks do also contribute to the problem just described above.
5. There is a need for conceptual change-based pedagogy to reduce any alternate conceptions instructors hold about the heat concept in an effort to improve chemistry instruction on this important topic. Instructors may need suggestions and resources for explaining the heat concept more accurately and appropriately.

Language is a powerful method of representation of knowledge and ideas in chemistry. The main purpose of this chapter is to demonstrate how language presents some difficulties to chemistry instructors as they teach the heat concept. Chemistry instructors and researchers are quite aware of the difficulties students have by confusing or inaccurately expressed language (Brookes, 2006). Even instructors who thoroughly understand the concept they are teaching have a difficult time passing on their intended meaning due to the constraints of the language used. Instructors discuss scientific concepts and ideas with students using 'everyday' words alongside precise scientifically accurate words to get across their meanings. I argue that this is where some of the confusion and mix-ups occur. The 'everyday' and natural language is full of alternate conceptions that can be misconstrued, such as the terms buffer and buffering. Students find meanings in the words from the sum of their previous experiences, connections, and situations in life (Nakhleh, Lowrey, & Mitchell, 1996). Often the words have different meanings for instructors and students, such as, distinguishing between the concepts of dissolving and solubility. This is an implicit and serious barrier to learning. I think it is likely that alternate conceptions will be dominant for a long time to come unless critical conceptual change occurs.

It therefore becomes very important to both analyze the language chemistry instructors use when talking about this concept to students as well as to study textbooks used in the classroom. I posit that alternate conceptions may be driven by how ideas are represented to students by their chemistry instructors. I show how the language chemistry instructors use about heat may directly influence students' reasoning about this topic. For example, I illustrate, using the data, why students might incorrectly regard and think about heat as a substance. It is difficult not to describe physical states without using metaphor and analogy; grammatical analysis shows heat being thought of as a non-living entity or thing, and not a process. Many examples and metaphors depict heat as a particular or specific substance within or out of a container.

4.2. Analysis

(i) Introduction

Raskin (2001) maintains all constructed meanings reflect a point of view. Through the process of social constructivism knowledge is negotiated between instructor and students within a given context and time frame; therefore, the role of language is considered crucial. Brookes (2006) specifies from his study that over 80% of the time, physicists talk about heat grammatically as if it were matter. The scientific consensus is that heat should be explained as a process and instructors should not be permitting students to reason or develop thoughts as if it were matter (Veiga, Duarte, & Maskill, 1989). I am suggesting that the use of metaphorical language by chemistry instructors likely presents many misconceptions to students. I argue that a problem is created in the minds of chemistry students' as soon as instructors use the verb 'is' when they mean 'is like' in a grammatical process of identification.

(ii) Research Study Problems and Difficulties

There were a few difficulties I had to consider before I analyzed the data from this research study. To begin with, instructors from only three of the nine institutions initially contacted in British Columbia and the Yukon agreed to participate in this research study. Even though this study represents a qualitative study there is a possibility that this 'slice of data' is not representative enough to consider for definitive analysis. It is possible that participants researched and rehearsed their responses to the audio recordings and survey-questionnaire; I had no way to ensure this did not happen. One instructor mailed in detailed 'notes' in this regard implying this notion. One participant completed a written response to the survey-questionnaire and then verbally expressed to me that they had "nothing relevant to say about heat in an audio recording" and preferred verbally to explain their conceptualization of heat face-to-face.

Technically, some participants found that their audio recording files were too large to electronically mail in and asked for advice on using a compact disk or flash drive device to send in their data. In addition, two participants clarified that they interpreted the meaning of diagram 3(b.) in the survey-questionnaire as masses (additional material of a substance) being added to the system which was the original intent.

(iii) Process

My data emanates from three sources: audio digital recordings and written responses from a survey-questionnaire obtained from nine practicing chemistry instructors in British Columbia, as well as eight chemistry textbooks used in the classroom by these instructors.

Below, I offer the analysis of each source of data. The process of analysis encompassed:

1. Listening to each digital recording received and carefully transcribing the verbal information into written form so that notes could be made for classification and coding of statements.
2. Reading each written response received and categorizing the information according to the instructor-held concepts, listing all resources mentioned for teaching the heat topic, documenting all responses to the instructors' textbook analysis, and tabulating the demographic information supplied.
3. Obtaining a copy of each textbook used by the participant for teaching in class, and then reading and examining a 'heat' unit if present. I took notes and organized information by category.

(iv) Audio and Written Response Analysis

The principal reference examples used by participant-instructors in their audio discussion about the heat concept, and the categorization of the number of instructors using each type of reference example is specified in Chart 1 (p.59). The following lists some examples as verbally expressed by instructors:

Kinetic/Bonding

- Heat gives molecules increased movement; bonds break.
- As heat energy is increased molecules move around with greater velocity.

Boiling Point

- Boiling point is the latent heat of vaporization for a substance.
- As temperature increases, water turns from a liquid into a gas and it boils.

Work

- It takes work to increase temperature in a system.
- Heat, like work, is a transfer of energy when an object is moved by a force.

Historical Reference

- The old Caloric Theory is not accurate.
- Joseph Black is in error when he said heat is latent; heat is not a fluid nor stored in a fluid.

Temperature Change/Thermometer Use

- Temperature changes when heat is transferred from object to object.
- Temperature can be measured by a thermometer; thermometers absorb heat.

Specific Heat (Capacity)

- Heat is applied to things according to the specific heat capacity of water.
- Specific heat capacity is a physical property; substances vary in how they absorb heat.

Forms/Types of Energy

- Heat energy is transferred by radiation, conduction, or convection.
- Molecules have rotational, vibrational, and/or translational kinetic energy.

Key points from my analysis are:

- All participants thought that kinetic molecular modeling, bond formation, and temperature change, as measured through the use of a thermometer, were very important aspects of heat concept development for instructional purposes.
- All participants used a reference to a kinetic molecular model and the forming and breaking of bonds in their discussion.
- All participants but one talked about temperature change or thermometer use.
- Interestingly, only one participant made any reference to an historical basis for concept development.
- Although the survey-questionnaire included a question asking for a response concerning ‘work’, diagram 3(b.) – piston/gas illustration (p.83), only three out of nine participants used ‘work’ as a reference for consideration.
- Specific reference to boiling point, specific heat capacity, and different forms of energy elicited a mixed response (63% of participants used each type of example).

I present a language analysis of instructors’ heat definitions in Chart 2 (p.59).

- All instructors explained heat using a description of physical energy as opposed to living or biological energy.
- With respect to alternate conceptions three instructors defined heat using a noun talking about heat as nonliving matter.
- Four out of nine instructors used a hybrid/blend of nouns and verbs to explain heat to their students, for example heat is ‘something’ transferred from object to object.

I illustrate the use of instructors' language by categorizing metaphor pieces into nouns, verbs, and prepositions and tabulated the information in Chart 3 (p.60). The parts of the metaphor can be separated into type of definition or meaning. Examples of instructors' language separated into the ontological classifications are:

Matter-Nonliving

- Heat is a form of energy.
- Heat energy is something added to break bonds.
- Heat is like a fluid.

Process

- Heat is a process of flowing from an object of higher temperature to one of lower temperature.
- Heat causes molecular bonds to break.
- Heat is a transfer of energy from an object of higher kinetic energy to one of lower kinetic energy.

Matter/Process

- The amount of heat is transferred.
- Some energy is released after transfer.
- Heat is something that flows by transfer from object to object.

State (Physical Energy)

- Molecules absorb heat energy to break away from each other.
- Energy is required to physically lift up masses.
- It takes energy to break bonds and phase change a substance.
- Heat capacity is a physical property of the system; each substance has its own value.

State-Function

- Change in the measure of the heat in a system equals the product of mass, specific heat capacity, and change in temperature.
- Thermal energy changes in a system during a reaction.
- Heat flow can be calculated after equilibrium by measuring amounts before and after a reaction.

Important points of my analysis are:

- The language instructors used to explain heat was mainly made up of verbs, like 'flows' or 'spreads' suggesting a meaning of fluid-like movement.
- All instructors used a physical reference talking about phase change of substances from solid to liquid to gas forms.
- Only one instructor discussed the heat concept with respect to a state-function description, that is, looking at only initial and final changes in a system.

The responses from question 3(a.) from the survey-questionnaire [heat energy applied to a beaker of pure water (p.82)] include phrases or sentences such as:

- Energy flows, or is transferred through, the bunsen burner apparatus from an object, like the flame, to another object.
- Intermolecular forces, such as hydrogen bonding, are disrupted and broken between the molecules of water.
- As the temperature increases bubbles form, the water boils, and phase change occurs; work is involved in this process.

I found that the responses for question 3(b.) [additional masses added to an ideal gas contained within a cylinder having a frictionless piston (p.83)] were varied and conflicting:

- One participant had no idea how 'work' fit into the heat concept at all.
- For the most part the instructors agreed that when additional masses of a substance were added to the system the pressure increased and the kinetic energy of the molecules increased as well.
- Four instructors believed that heat would evolve or be released from the system.
- Two instructors thought that temperature would change but could not or did not explain why.
- Four instructors talked about how the temperature would not change as heat did not evolve within a closed system.
- Several instructors suggested that the Ideal Gas Law is relevant, and should be discussed in connection with heat.
- One instructor elaborated on the work required to increase the temperature to eventually effect the phase change of a substance.

When answering question 3(c.) [a temperature/time graph for water (p.83)], as illustrated in Chart 4 (p.61), I noted that all instructors discussed the idea that heat energy was being input to the system through a transfer process causing the kinetic energy of the molecules to increase.

- As this process occurred intermolecular bonds were being broken which resulted in phase change of the substance.
- All instructors tenaciously explained that the plateaus on the graph indicated that although heat energy was being input to the system, the temperature would not increase until all intermolecular bonds were broken and all molecules had changed phase.
    - One instructor talked about specific heat capacity with reference to the graph in the question and three instructors elaborated on types of heat energy, such as heats of fusion and vaporization, with regard to changing phase.

Examples:

The following examples from this study illustrate a hierarchy of definitions and explanations for heat in ascending order from the most basic to the most developed (as verbally expressed by instructors):

- Heat is a form of energy.
- Heat is a transfer of energy.
- Heat flows from object to object.
- Heat moves from the flames of the bunsen burner into the water.
- Heat moves from object to object by conduction and convection; it is a process.
- Heat is transferred in to or out of a system.
- Heat causes molecular bonds to break.
- Heat is a transfer of energy from an item with more kinetic energy to an item with less kinetic energy.
- Heat is one of the methods that allows for energy transfer by two bodies in contact having a change in temperature.

In addition…

- Energy is transferred when an object is moved by force.
- The concepts of work and energy are one and the same.
- Heat is one method by which internal energy can be changed and this is called work.

Alternate Conceptions

The following are examples of instructor-held faulty and alternate conceptions regarding the heat concept from this study:

- Heat is an amount.
- Heat energy is something physical with a certain value which can be calculated.
- Heat is latent.
- Heat energy is something added to a substance to break its bonds.
- Bubbles from boiling water created by the bunsen burner cause molecular movement.
- Heat provides molecules with motion.
- Heat flows from hot objects to cold objects.
- Heat is the transfer of energy from an area of lower to higher temperature.
- Particles take energy with them when they move.
- Heat is some thing liberated from a chemical reaction.
- Heat is the sum of all energies that molecules possess.

- Work has an unknown connection to heat

Extension of the Issue

The following provide examples of how two instructors sought to clarify the issue realizing the difficulties of language, and the alternate conceptions of heat that students might possess. They articulated:

Heat is not…

- a fluid
- latent or contained
- an absolute value – it is difficult to measure
- matter with mass and occupying space
- a noun but instead a process (grammatical reference)
- agreed upon by all scientists (interdisciplinary reference)

and…

- objects do **not** have heat or temperature
- objects do **not** have kinetic energy

Resources and Teaching Strategies Utilized to Explain the Heat Concept and Motivate Students

- laboratory demonstrations and activities on boiling points of various substances, such as water
- demonstrations using thermometers
- specific calorimetry (bomb) experiments and activities for thermodynamics, for example using insulated coffee cups
- exothermic and endothermic activities to compare reaction types, such as with acids and bases or 'miracle-freeze' infomercial demonstrating the thawing of a steak
- specific heat capacity experiments, such as using different metals of varying sizes
- experiments proving Hess' Law
- distilling apparatus
- thermal expansion demonstrations, for example, examining railway ties at various temperatures
- pressure experiments, for example, balloon demonstrations, or watching a bag of potato chips moved from lower to higher elevations
- diagrams from class textbooks, such as illustrations and graphs, showing molecular structure and phase change
- molecular model kits
- animated videos, such as the 'Eureka' series
- links to web-based materials from class notes
- oft-repeated queries to students in class to determine their thinking processes

(v) Textbook Analysis

In Table 1 (p.63) I compare and contrast the eight textbooks analyzed for specific and type of definition given for heat and temperature, illustrations and modeling of the difference between heat and temperature, as well as any interpretation of absolute zero or scale. Two textbooks do not provide a definition of heat at all, yet they contain units involving molecular mobility and kinetics. Three textbooks give no definition for temperature, while only one textbook (Wilbraham, Staley, Matta, & Waterman, 2008) illustrates or diagrams the difference between heat and temperature. All but two texts (Hebden 11/12, 1998) interpret and explain the concept of absolute zero. I find it noteworthy, however, that of those texts providing a definition of heat, the concept is defined as a process using verbs grammatically while one text (Herron, Kukla, Schrader, Morrison, DiSpezio, Erickson, & Scodellaro, 1987) chooses to explain heat using a hybrid/blend of operational-nouns and process-verbs.

In Table 2 (p.65) I depict a comparison of eight chemistry textbooks placing the given heat clauses into various ontological categories. Only one textbook (Petrucci, Herring, Madura, & Bissonnette, 2011) does not classify heat as matter. Wilbraham et al. (2008) uses language that is very clear but the authors define heat as either matter or as a process. All of the texts I surveyed, but one, use a blend of grammatical terms and clauses. An example of this heterogeneous formation would be 'an exothermic reaction involves heat exiting the system; heat is a product in the reaction' (Herron et al., 1987; Zumdahl & DeCoste, 2011).

In Table 3 (p.66) I present a hierarchy of simple to more complex conceptualizations of heat as classified by the eight textbooks from my survey. All but one text (Petrucci et al., 2011) periodically uses language that illustrates heat as a substance. Petrucci et al. (2011) does, however, provide a better scientific use of language as, not only do the authors discuss what heat is, but also what heat is not. Zumdahl and DeCoste (2011) also proceed in this direction as they stipulate that heat is not a state function, instead heat depends on a specific pathway followed.

In Table 4 (p.68) I record instructors' reflections on the chemistry textbook they use in class. The instructors were asked only to examine a heat unit (if present) in the textbook. One text (Hebden 12, 1998) does not contain a heat unit. Three instructors found that the text they used in class did not adequately explain heat. These instructors suggested language improvement and more examples were needed. The other instructors said they did find the text used in class adequate or effective in presentation of the heat concept. However, one instructor did explain the need to simplify the text material for students. It was surprising and disconcerting for me to note that two instructors recorded no heat unit being present in the text they used in class, and yet I did find a substantial unit on heat present in those texts.

Examples:

The following are the best scientifically accepted explanations of heat as found in my textbook analysis:

1. Heat is energy that transfers from one object to another because of a temperature difference between them in a system. (Wilbraham et al., 2008)
2. Heat is not a substance but instead a form of energy in which a quantity of energy may be transferred across a boundary between a system and its surroundings. (Petrucci et al., 2011)

Alternate Conceptions

The following are prime examples of textbook alternate conceptions (with my evaluation) regarding the heat concept as surveyed in this study:

- Heat is some thing added or removed; heat is not a substance.
- Heat is a form of energy (with no further explanation); heat is more than just a form of energy.
- Heat is a product or reactant in a chemical reaction; implies heat is a thing or substance.
- Heat exits from reactants when bonds are broken; implies heat is flowing out.
- Heat flows from object to object; heat is not a fluid, nor a liquid.
- Heat is a process of moving some thing from one object to another; heat is not a substance.

4.3. Discussion and Summary

The conceptualizations of heat from the sample of chemistry instructors I investigated, and the textbooks surveyed in this research study, include:

1. Many chemistry instructors hold alternate conceptions with respect to the teaching of the heat concept, for example, expressing heat as latent.
2. Instructors without a major in chemistry more frequently express heat as a substance in their teaching, but this statement is inconclusive because of sample size.
3. Chemistry instructors frequently use a mix of substance and process terms in their teaching of the heat concept.
4. Instructors often use inappropriate cue words, such as ‘flows’, which infers a fluid or liquid when speaking about heat.
5. This study illustrates a variety of ways in which chemistry instructors construct steps into the building of the heat concept for their students. The construction process may be composed of few or multiple steps.
6. Only some instructors understand the applicability and limitations of their language as they speak and reason about heat using a coherent system of examples, metaphors, and analogies in their teaching. These instructors carefully talk about what heat is ‘not’. For example, heat is not matter, nor is heat latent as heat is not stored in, or as, a fluid.

7. The language used in chemistry textbooks varies, and generates alternate conceptions in their treatment of the heat concept, such as considering heat as a 'product' in an exothermic reaction.
8. In this study seven out of nine instructors expressed a general satisfaction with the manner in which the heat concept was explained in their classroom textbooks.

I have illustrated with Figures 1 and 2 (p.69) a summary of the emergent theories produced from my data analysis of the language of chemistry instructors and textbooks. The concepts from this study are diagrammed using construct blocks.

Heat should be thought of as a process rather than a substance. In this study many instructors' language did not reflect this understanding. Brookes, Horton, Van Heuvelen, & Etkina (2004) reported similar findings. From this study it is evident that chemistry instructors tend to grammatically mix substance and process terminology when they talk about heat in the classroom. Many instructors began their discussion defining heat as an 'energetic substance' thereby inferring that heat is an object or thing. This is considered an alternate conception in the currently accepted scientific realm. Also, many instructors use contradictory or misleading statements when they speak about heat. They use language darting back and forth between examples and metaphors regarding heat as some form of energy (an entity or thing) to something that flows by transfer from object to object (a process). The language chemistry instructors use about heat may directly influence students' reasoning about this topic. In support of my work Galili and Lehavi (2006) also found that a sample consisting of experienced physics teachers had accrued definitions of heat and temperature that were either incomplete or consisted of alternate conceptions, therefore being inconsonant with currently accepted scientific views. Alternate conceptions might prevent students from solving heat-related problems in chemistry such as in the study of thermodynamics. Quilez-Pardo and Solaz-Portoles (1995) claim students' problem-solving strategies with equilibrium problems involving heat are influenced by teachers' conceptions and alternate conceptions.

Teaching experience did not seem to matter with regard to having alternate conceptions for heat as much as type of major in university education. The instructors majoring in chemistry frequently talked about heat grammatically using a noun-substance in discussion or blended their descriptions with noun-verbs. I am maintaining that any use of a noun, such as 'amount', signals a 'substance' meaning which is an alternate conception as well this infers heat is not a liquid.

Many of the textbooks I surveyed use unclear and misleading language when explaining the heat concept. I found that the texts I examined typically use a blend of grammar and language creating a very confusing idea of heat. The study by Galili and Lehavi (2006) supports this finding. As well, Sozbilir (2006) concludes in his study that one possible source of alternate conceptions or misunderstandings could be the definitions of terms in textbooks. It is currently accepted by the scientific community that heat is a process involving the transfer of energy from one system to another based on certain conditions.

4.4. Final Results

Instructors predominately teach chemistry at a highly symbolic and abstract level whereby without the use of analogies or models chemistry would not be understood (Gabel, 1999; Heyworth, 1999). In this chapter, I have demonstrated that the combination of grammar, ontology, and metaphor reveals patterns of inconsistency in chemistry instructors' language revealing many heat-related alternate conceptions. This uncovers underlying patterns in the way heat is expressed in teaching. I have tried to illustrate how grammar and metaphor work together to encode the features of a particular idea or concept. Any alternate conceptions are in danger of being passed on to students by their instructors (Taber, 2002; Kruse & Roehrig, 2005).

If instructors ground their ideas (using models, metaphors, or analogies) in physical or experiential models of the world, that grounding is expressed in language and other representations, such as animations, which may be constrained by language and other representations. I argue that instructors must be very careful when they speak in class through the teaching process. Language users must individually construct the meanings of words. Learning is dependent upon language and communication. Therefore, language must have meaning; it is not a source of transferring information (Yager, 1991). Students may be taking cues or receiving alternate conceptions from the way instructors speak in class (Brookes, 2006). I suggest chemistry instructors' language does not make the ontological distinctions clear. The basis of this will be the point of consensus that heat is not a thing, but a process. In this study many instructors use inappropriate cue words in their discussion of the concept. Students when trying to interpret the language of their instructor do so literally rather than figuratively because instructors are not specific and accurate enough in their language and explanations (Lemke, 2004; Brookes, 2006). I argue that this way of speaking is very confusing to chemistry students trying to make sense of the concept.

I have observed from my teaching practice that textbooks often represent a higher standard of linguistic rigor, such as reading level, than instructor conversation in the classroom and laboratory. Therefore these books represent a higher limit on the quality of language used when discussing the heat concept (Brookes, Horton, Van Heuvelen, & Etkina, 2004). However, problematically the language used in the chemistry textbooks, from my review, contains incorrect grammar to convey the scientifically accepted meaning of the heat concept. In this chapter I have also shown that chemistry textbooks are also a potential source of alternate conceptions concerning the heat topic through the faulty and confusing language they use. Taber (2000b) agrees with this finding suggesting that alternate conceptions likely result from the unfortunate way textbooks use a wide range of different terms for explaining energy, including heat.

Chapter 5: The Conclusions

In this chapter I summarize and interpret the ideas and results presented in this thesis. I provide suggestions and resources for instructors to aid in a more accurate teaching of the heat concept through conceptual building and change. I also discuss implications for improving instructional practice and textbook writing, as well raising questions, and proposing possible directions for future research.

5.1. Summary

Constructing scientifically accurate concepts in chemistry is not easily accomplished and it is widely acknowledged that students hold misconceptions about a wide variety of scientific concepts. In this study I have presented how preconceived chemistry concepts, actively built by instructors, may be alternate conceptions because both background and a working knowledge may be lacking in the conceptualization of heat. There are many misconceptions and alternate conceptions regarding this concept especially since I found no universal explanation for heat that all chemists agree on. There is a necessity for alternate conceptions to be identified and replaced with, or developed into, more scientifically acceptable concepts. Instructors need to be aware that they may be sources of alternate conceptions with these alternate conceptions being in danger of transfer to chemistry students if instructors are not aware of the problem. I argue that chemistry instructors need to identify and understand these alternate conceptions and find ways to counteract them before passing these incorrect ideas on to students. Understanding the heat concept in chemistry is crucial to understanding many other scientific concepts. Heat and temperature are considered among the most difficult concepts in the secondary science and university curricula (Sozbilir, 2003). My review of the literature suggests instructors hold and use many alternate conceptions, in their efforts to instruct heat, which are often discrepant with the accepted views of the scientific community. The results of my study are in agreement with this notion.

My investigation finds chemistry instructors do hold incorrect and faulty ideas about the heat concept. Some chemistry instructors define and explain heat as little more than an energetic substance. Other instructors reach beyond this point and regard heat as a process of energy flow. Some instructors discuss heat with a grammatical hybrid/blend of nouns and verbs, for instance, defining heat as something energetic transferred from object to object, or in and out of containers. The highest level of construction attained from this research study was one where instructors reasoned about heat using the concept of work, such as ‘heat energy is an entity capable of doing work’. This level of thinking was expressed more frequently from those sampled instructors who have a stronger background in chemistry.

In addition, my investigation finds chemistry textbooks do contain incorrect and alternate conceptions about the heat concept. In this study I discovered that, of the textbooks analyzed, several texts grammatically blended substance terms with process terms when writing about heat. There were many incorrect phrasings and vocabulary given in these books, for instance, referring to heat as a reactant or product in a chemical reaction. However, notably, the first-year chemistry text, Petrucci, Herring, Madura, & Bissonnette (2011), does present an upper level of scientific expression and thinking regarding the heat concept as evidenced by the authors using vocabulary generally consistent with the current scientifically accepted explanation of heat.

In this thesis I have used the methodology of grounded theory to develop a new perspective on how knowledge is structured or constructed in the language used by chemistry instructors for teaching the heat concept. Grounded theory is a research methodology that, through repetitive cycles of data collection and constant comparative analysis for emergent themes, develops theoretical explanations of social phenomena which are grounded in practical experience. I have described a linguistic view of teaching heat and temperature in terms of process versus object vocabulary.

The use of grounded theory in this thesis is important because it illustrates and examines instructors' use and meaning of heat and temperature in everyday teaching experience. I have tried to overcome the deficiencies of this methodology which may include application of predetermined themes rather than allowing theories to naturally emerge, description of topics instead of indicating resultant theory, depiction of false interconnections between evidence and interpretation, and possibly over-generalization of themes due to small sample size. However, Taber (2000a) puts forth that a valuable outcome of this type of methodology would be producing testable results leading to predictions which may be subject to traditional experiments and statistical testing. I am not saying that instructors or textbooks are the sole sources of alternate conceptions possessed by students. The goal of grounded theory is not to explain everything, but to determine a region of application. I posit that grounded theory allows the research a way to bridge the gap between individual authenticated accounts and generalized accounts of a concept, while offering meaningful advice for instructors and curriculum planners. I suggest grounded theory can be complemented with instructors' entire lessons traced and examined through Toulmin's model of argumentation.

I conclude from this study that grounded theory effectively: (i) identified and uncovered concepts and alternate conceptions held by nine chemistry instructors teaching the heat concept, (ii) revealed that instructors often defined and explained the term 'heat' inconsistently and inappropriately in the classroom teaching process, (iii) showed that chemistry instructors' language used physical models and metaphorical representations based on common language which contains alternate conceptions, (iv) illustrated that the ontology used by chemistry instructors may confuse students as the inherent alternate conceptions may affect students' reasoning powers about heat-related problems.

5.2. Educational Implications

I have demonstrated, from this research study, that unconsciously, scientifically incorrect ideas, or alternate conceptions, held by instructors may be passed on to their students. I have also explained how language is a powerful method of representation of knowledge and ideas in chemistry education.

Alternate conceptions may be spread through inaccurate articulation and misuse of the metaphorical device. One of the problems is that metaphor and analogy are often limited and may not always be applicable. However, without the process of making sense of the unfamiliar in terms of the familiar by using metaphors and analogies, science as we know it could not take place (Brookes, 2006). The textbooks I have analyzed show how writers need to improve and support their language with accompanying diagrams and models to express a more scientifically accurate conceptualization of heat and temperature.

I suggest that chemistry instructors need to set aside their own preconceptions and alternate conceptions thereby allowing their students to perceive the most current scientific reality. There can not be a 'kind of truth' in the accurate building of the heat concept if instructors want students to be successful in the study of chemistry. I contend that the linguistic component of context should be examined more closely. I posit that chemistry instructors should better articulate their ideas so that there is less of a gap between what is figuratively and literally meant so as to improve conceptual understanding of heat. If instructors are unaware of the difficulties students experience interpreting metaphorical scientific language, it leaves them less able to understand, interpret, and facilitate student learning. Alternate conceptions may arise from this confusion, that is, the language the students hear is taken too literally. A constructivist viewpoint is greatly informed by alternative conceptions in science, however, Toulmin's notion of 'conceptual ecology', that is, the intellectual environment provides an ecological niche which will differentially support possible conceptual changes, is also relevant (Ogunniyi & Hewson, 2008). The wide range of features making up such an ecology, such as analogies, metaphors, past experiences, competing conceptions, and explanatory ideas are helpful.

It is important for instructors to more carefully identify the matter, processes, and states of any particular model used and speak with language consistent with the lexical ontology of the model. Can we speak more carefully? Can we say for example, not 'heat broke the bonds of the substance, but 'the molecular bonds of the substance were broken by heating'? Instructors should also clarify ambiguous language, especially from the textbook, and discuss the limits of any metaphors used in instruction. The idea of heat as a process quantity directly contradicts the forms of energy language. Instructors need to speak about heat as a process, not as a thing; textbooks should be defining heat using process terminology. If instructors have a deeper understanding of the heat concept this more scientifically accurate understanding has a greater chance of being passed on to their students.

I propose that instructors may find it useful to bridge the gap between a common idiomatic with heat expressed in everyday experience with a more accurate scientifically accepted language. In popular speech the word heat has wide range of meanings with metaphors grounded in everyday experience, for example, a 'hot' topic is a controversial one, and 'cold' runs through the nerve canals in our mouths causing pain alleviated by using specially made toothpaste created for sensitive teeth. Chemistry instructors might build wording and meaning from common everyday language (possibly containing alternate conceptions) to more accurate scientifically accepted meanings with an ‘intermediary language’ by way of transition. Students might better grasp concepts through this process. This is not a new idea! Kaper and Goedhart (2002) hypothesize that a good ‘intermediary language’ should consistently, and with validity, describe and/or predict phenomena within a specific set of experiences. It should also be organized and sequential in that the language should begin with everyday terminology and expression, and culminate in currently approved scientific language. Veiga, Duarte, and Maskill (1989) also suggest bridging the two languages together. They put forth that the natural common language used by the teacher in class impedes learning as this language contains scientifically inaccurate and incorrect ideas and reinforces the problem. I argue that it is impossible for instructors to always use scientific terms in class without also including common daily language as they try to convey conceptual meaning in the classroom or laboratory. A form of language is needed that could avoid common linguistic references and might continually use qualifying comments, such as, “I mean… when I say…” to avoid misconceptions between any disconnect that is occurring.

Language, as a representation, does not function in isolation (Brookes, 2006). If different representations and meanings of the same concept are given by instructors to their students, then students may leave class and the laboratory confused, and possessing alternate conceptions. Practical implementation through aids and resources, such as animations and graphical representations devoid of alternate conceptions, may help alleviate this problem. As well, historical case studies are a useful tool for incorporating the nature of scientific perspectives and understandings related to what is known about a concept. As instructors we should be exploring the language students read and hear, and analyzing the language by picking out the underlying metaphors and ontology in that language, as well as looking for correlations between models implied by the ontology/metaphors of any questions we ask in chemistry. I argue for instructors to make students aware of the notion that models, examples, and metaphors only bring into prominence and characterize specific parts or aspects of intended meaning of a concept. Regarding heat, a wholesale shift in representations, from language to textbook diagrams misrepresenting objects and processes, to those that correctly represent them, is really necessary. Instead of always naming and defining terms first, instructors might explore and look at the applicability and limits of any metaphors and models they use in the teaching process.

I submit that either we, as instructors, be very clear about the language we use, or introduce a new transitory language activating a different metaphorical system which would serve our pedagogical purposes better than the current language used. Kaper and Goedhart’s (2002) intermediate language proposal – one of limited validity and grounded in everyday experience but peppered with good examples – would facilitate a transition from everyday experience to accepted scientific understanding. Humans interpret what they see through the language they speak with reality mediated by cultural metaphors. I maintain it is important to distinguish among ‘what we take to be true’,‘what we take to be real', and 'what we take to be of value' in the teaching/learning environment.

5.3. Future Research

I have shown in this thesis that there is improper use of language by instructors and textbooks. This could explain why students may find thermal chemistry so difficult to understand. It is critical for students and instructors to build scientifically accurate concepts in an effort to contest and reduce faulty alternate conceptions and help effect conceptual change. I have shown for chemistry instructors the requisite to reflectively examine and reduce any alternate conceptions being possibly passed on to students during instruction and effect conceptual change where possible.

It is difficult to say how much of students' problems regarding the heat concept may be caused by language that chemistry teachers use in instruction. The verbal evaluation process, and the text analyses, provide a series of events of conceptual conflict to provide instructors with an opportunity to challenge their scientific concept of heat. Does it matter how instructors ask questions of their students? Will rephrasing the query permit students to respond differently? Conceptual change perspectives provide a potentially powerful framework for significantly improving instructional practice. Constructivism views all of the various elements in a learner's conceptual network as subject to progressive knowledge construction. I suggest the tone of constructivism can be improved in many ways, such as, utilizing the revision and reorganization of ideas to strengthen a particular conceptual network for improving instructional practice and textbook writing. Instructors and textbook writers should frequently use open-ended questions, encourage students to test their own ideas, and also encourage students to challenge each other's conceptualizations.

Hopefully this research study will provide benefits for chemistry instructors, science education researchers, curriculum developers, textbook writers, and others doing scholarly work in science education working towards a more accurate understanding of the heat concept. My research may also help look for sources of students' difficulties, find effective teaching strategies, and aid pre-service instructors in lesson preparation. I would like to see improved understanding and communication between chemistry instructors, and their students, with new insights provided into alternate conceptions preventing better learning of chemistry in the classroom and laboratory. More time needs to be spent on reviewing the literature to establish the impact of alternate conceptions of various types and origins on science instruction. As well, more research needs to be conducted to determine how ideas are put together on a human cognitive and/or neurological level for effective construction of scientific concepts. More work should be conducted on larger sample sizes involving chemistry instructors and their students. There are unexplored avenues for making predictions about student difficulties, formulating teaching strategies to overcome and solve these difficulties, and increasing aid to novice, or out-of-discipline instructors, about heat. Textbook definitions of heat do not comprise or represent a complete pedagogical presentation of the concept, however, they do often serve as a principal source for instruction (Doige & Day, 2010). Conducting more interdisciplinary and cross-disciplinary work on textbooks is warranted. I submit all of these ideas need to be further tested. Such initiatives will promise more meaningful learning for students.

Charts

Chart 1: Audio Discussion Reference Examples – Used by Instructors in Explanations

Kinetic/ Bonding Model	Boiling Point Explanation	Work Relevance	Historical Reference	Temperature Change or Thermometer Use	Specific Heat (Capacity)	Forms/Types of Energy
Yes 9	Yes 5	Yes 3	Yes 1	Yes 8	Yes 6	Yes 6
No 0	No 4	No 6	No 8	No 1	No 3	No 3

Chart 2: Language – Ontological Classification of Heat

Matter - Nonliving	Process	Matter/Process Blend	State	State-Function
Noun	Verb	Noun & Verb	Physical (energy)	Explanation/data
3	2	4	9	1

Chart 3: Language – Words Cueing Metaphors

Part of Metaphor	Nouns	Verbs	Prepositions and Prepositional Phrases
Substance	something, a form, amount, specific quantities, a certain value, sum (all) of, all of, lots of, types of, physical entity		
Movement		applied, changing, causing, is transferred, forming, breaking, being done, is done, move, interacting, causes expansion, molecules vibrating, given off, taking, absorbed, flows, exchanged, feel, adding, gained, spreading, evolved, released, removed, liberated, increased movement, molecular bond breaking, is produced, is supplied at a constant rate, is converted to molecular motion, molecules possess heat, doing work	over, to, from, in, with, by, out, due to, off, of, between
Container	surroundings, system	is added, removed, in contact, leaving, escaping, is taken, is transferred to (or out of, within, surroundings) a system, affects molecular motion (within) molecules possess heat, flows from object to object, goes into system, enters or exits a system,	to, in, out of, into, from, within, input
Movement/Container Blend		is transferred, given off, taking, absorbed, is exchanged, feel, adding, gained, spreading, evolved, released, liberated, produced,	

Chart 4: Language - Framing

Reference Frame			
an energetic entity (a substance)	**flows (fluid-like)**	**functional (causes something to happen)**	**process clarity extension**
is absorbed, added or removed, a form or type of energy, sum of all energies molecules possess, produced, supplied at a constant rate, given off, quantity of energy, total energy (potential + kinetic) in system, amount (a lot) of energy transferred, energy is released or input, a measurable thing, a quantity, evolved, liberated, absorbed, a physical property having a certain value	moves from flame to water molecules, transferred, exchanged, transferred from one item with more kinetic energy to one with less kinetic energy (by a difference in their temperatures), flows into or out of system, particles take heat energy with them, is absorbed by thermometer, moves from object to object by conduction, convection, and radiation, transfer of energy from an area of lower to higher temperature in a system, energy is added in to or out of system, flows from a hot to a cold body	causes increased movement of atoms and molecules, sum of all energies related to molecular motion or movement, provides molecular motion, causes phase change, causes disruption of intermolecular forces, breaks bonds, causes temperature change, causes molecules to vibrate, affects matter, is applied according to specific heat capacity of substance (water), causes electrons to move outward from nucleus – expansion, affects/causes molecular movement, causes energy transfer by radiation, conduction, and convection, or causes above, if added molecules increase kinetic energy, work/energy is required to increase temperature causing phase change	two bodies in contact having a change in temperature due to heat transfer but energy transfer does not always result in temperature change, force(s) applied over a distance (work), heat is transferred when an object is moved by a force, concepts of work and energy are one and the same, heat energy is an entity capable of doing work but temperature does not always change

Chart 5: Sample Demographics

Teaching Experience	greater than 10 years	less than 10 years
	6	3
Chemistry Major	Yes	No
	4	5
Teacher Training	Yes	No
(one year)	7	2

Tables

Table 1: Definition Typing

Textbook	**Definitions of Heat and Temperature**	**Difference (illustrated/ modelled)**	**Type of Definition**	**Interpretation of Absolute Zero/Scale**
Chemistry Gilbert et al. (2009)	Heat – the energy transferred between objects because of a difference in their temperature Temperature – none	No	Process-dynamic; verb used	Yes; theoretically the lowest temperature possible
Hebden: *Chemistry 11/12- A workbook for students* (1998)	Not given – except for melting point, freezing point, and boiling point (phase change**)**	No – graphs given displaying temperature vs. heat on axes	Not applicable	Absent
Chemistry Herron et al. (1987)	Heat – a form of energy Temperature – a measure of average kinetic energy of molecules or the amount of heat per molecule of substance; not a unitary rate; not a form of energy	No – only kinetic energy Assumption described for equalizing heat	Operational-static and process-dynamic; noun and verb hybrid/blend used	Formula given; brief discussion by graph only
General chemistry: Principles and modern applications Petrucci et al. (2011)	Heat – is energy transferred between a system and its surroundings as a result of a temperature change Temperature – average translational kinetic energy of a collection of molecules	No diagram – text not clear for comparison	Process-dynamic; verb used	Yes – diagram provided

Table 1: Definition Typing (continued)

Textbook	Definitions of Heat and Temperature	Difference (illustrated/ modelled)	Type of Definition	Interpretation of Absolute Zero/Scale
Chemistry Wilbraham et al. (2008*)*	Heat – is energy that transfers from one object to another because of a temperature difference between them Temperature – a measure of the average kinetic energy of particles in matter; temperature determines the direction of heat transfer	Yes	Process-dynamic; verb used	Yes – formula given for conversion Kelvin temperature is directly proportional to the average kinetic energy of the particles of a substance
Introductory chemistry: A foundation Zumdahl (1996)	Heat – energy transferred between two objects because of a temperature difference between them Temperature – (only defined with reference to gases) – a measure of the motion of the gas particles	No – temperature conversion scales provided	Process-dynamic; verb used	Yes – with diagrams; the Kelvin temperature of a gas is directly proportional to the average kinetic energy of the gas particles
Introductory chemistry: A foundation Zumdahl & DeCoste (2011)	Heat – a flow of energy due to a temperature difference Temperature – a measure of the random motions of the components of a substance	No – temperature conversion scales provided	Process-dynamic; verb used	Yes – with graphs and diagrams provided

Table 2: Classification of Heat Clauses into Ontological Categories

Text	Gilbert et al.	Hebden (11)	Hebden (12)	Herron et al.	Petrucci et al.	Wilbraham et al.	Zumdahl	Zumdahl & DeCoste
Matter	√	√	√	√	x	√	√	√
Process	√	√	√	√	√	√	√	√
Clear Differentiation	x	x	x	x	x	√	x	x
State Function Terms	√	√	√	√	√	x	x	√

Table 3: Metaphorical Classification of Heat Clauses

	Metaphor	Gilbert et al.	Hebden (11)	Hebden (12)	Herron et al.	Petrucci et al.	Wilbraham et al.	Zumdahl	Zumdahl & DeCoste
1	Heat is a substance	adding heat, product or reactant, remove some, lost, gained	add heat to the sample, heat energy is contained in reactants or products	$A \rightarrow B$ + heat C + heat$\rightarrow$ D	a form of energy		add heat, remove heat (in a reaction)	amount of heat energy, this much, reactant, product (treat or regard as)	amount required, amount measured, amount associated with, treat as a product or reactant,
2	Heat is a substance that moves	moving heat, transfer, flow, remove some, absorbed, released	atoms when joining in bond formation give off their excess energy; heat exits from reactants when bonds are broken	if amount increases, reactions shifts producing more	absorbed from skin, transferred to molecules	transfer of thermal energy, heat is released, absorbed, evolved, added, removed	energy that transfers, absorbing, releases heat		producing, transferred, added, evolution of, absorbed, flow of, radiated
3	Heat is a substance that moves; and heat moves from container (system) to container (system)	process of moving heat from one object to another, is added, is removed, released from	add heat to the sample, system is closed to heat, heat flowing from system to surround-ings	heat exits the system	a substance with a high specific heat makes a good 'heat' sponge, heat exits system, flows spon-taneously from hotter to colder objects		heat is flowing in to or out of a system, system gains heat as surroundings cool down, heat moves from object to object		energy flows out of or in to a system as heat

Table 3: Metaphorical Classification of Heat Clauses (continued)

	Metaphor	Gilbert et al.	Hebden (11)	Hebden (12)	Herron et al.	Petrucci et al.	Wilbraham et al.	Zumdahl	Zumdahl & DeCoste
4	Heat is a process	causes phase change, causes temperature change in objects	molecules absorb heat		changes matter	result of temperature change, kinetic molecular theory due to heat, heat is converted to work	phase change is a result of heat	heat causes denaturation of proteins, changes the temperature, generating, calculating, producing, absorbing	potential energy is converted to kinetic energy via heat, flow of energy due to temperature differences
5	Heat is a process which involves the movement of a energetic substance; from one system (place) to another system (place)	process of moving heat, causes phase change in a system, energy transferred between objects because of a difference in their temperatures	molecules absorb heat from surroundings (endo-thermic reactions), liquid transfers heat to air	heat may be transferred into or out of system, loss of energy from surroundings to system	molecules absorb heat, energy randomly distributed energy	inaccuracies discussed- such as heat is not a substance- instead a form in which a quantity of energy may be transferred across a boundary between a system and its surroundings	heat is energy that transfers from one object to another because of a temperature difference between them (in a system)		the flow of energy called heat is the way in which thermal energy is transferred from a hot object to a colder object, heat flows in to or out of a system/sur-roundings

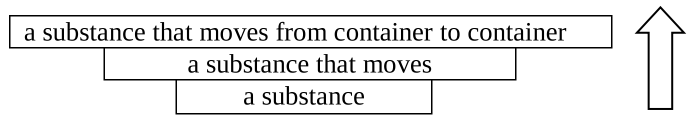
Table 4: Instructors' Reflections

Text	Heat Unit Present	Effective Presentation	Examples of Poor Explanation	Instructor Suggestions for Improvement
Gilbert et al.	Yes	No	1. calorimeter examples missing 2. incorrect phrases: • 'heat flows' • 'as it takes up heat from the liquid water' • 'heat from (material) is transferred' • 'most of heat lost…' • 'ability of water to absorb large quantities of heat'	1. language does not reinforce correct definition 2. change incorrect language/ phrases 3. provide more examples 4. needs a logical method to connect physical means to enthalpy
Hebden (11)	Yes but minimal (one section within a chapter)	Yes or not applicable	-	none
Hebden (12)	No	No	-	-
Herron et al.	Yes	Not entirely	-	-
Petrucci et al.	Yes (one instructor not aware of it)	Yes	-	- none - more visceral examples needed
Wilbraham et al.	Yes	Yes		needs more practice materials with answers
Zumdahl	No (small part of a chapter)	Yes	-"do not change"	"physics text used not accurate"
Zumdahl & DeCoste	Yes	Yes	-"text not used much"	"I simplify text's presentation"

Figures

Figure 1: Concept Blocks Formulated from Audio Discussions

(i) Heat is….



Or More Accurately…

(ii) …a process

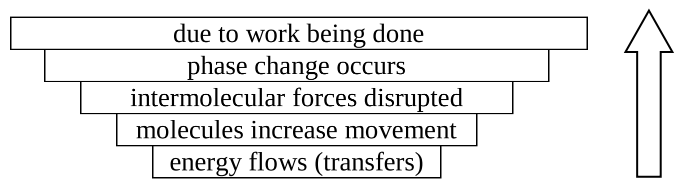
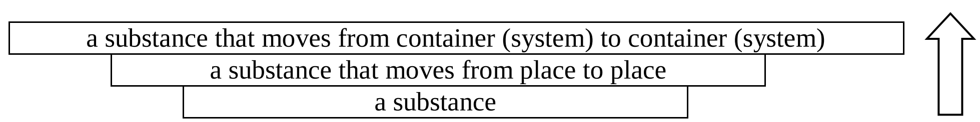


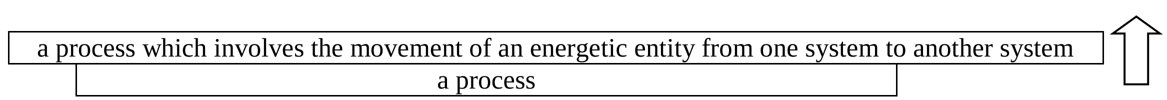
Figure 2: Concept Blocks Formulated from Textbook Analysis

(i) Heat is…



Or More Accurately…

(ii)



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Zumdahl, S. S., & DeCoste, D. J. (2011). *Introductory chemistry: A foundation* (7th edition). U.S.A.: Brooks/Cole, Cengage Learning.

Appendix A: Formal Letter of Invitation to Study Participants

THE UNIVERSITY OF BRITISH COLUMBIA

OKANAGAN

Faculty of Education
3333 University Way
Kelowna, BC Canada V1V 1V7
Tel: 250.807.9176 Fax: 250.807.8084
www.ubc.ca/okanagan/education

An Investigation into some Alternate Conceptions of Heat

Dear Participant

Introduction

I am an Okanagan College instructor and an Education graduate student enrolled at the University of British Columbia/Okanagan conducting research on the important topic of heat and temperature in chemistry. I am interested in finding out how instructors teach the heat concept within their respective practices.

As a chemistry instructor working in a college or university located within the province of British Columbia, you are invited to participate in this research study exploring that understands that chemistry teachers may have of this concept. However, your **participation is voluntary; you can withdraw your participation at any time.**

The Rationale

Through the lens of the teacher, I would like to determine instructors' conceptions of the meaning of the heat concept with specific reference to the way the concept is taught within chemistry. Understanding the that concept is key to understanding many other scientific concepts. For example, students' approaches to solving certain heat-related problems are partially influenced by the way in which they define the term heat. There are many misconceptions and alternate conceptions regarding this concept especially since there is no universal definition of what heat is that all chemists will agree upon.

In addition, I would like to correlate a textbook analysis with this research in order to compare the textbook language and usage with each instructor's conceptualization. The text is a tool that enables students to contract meaning, for this reason, understanding the chemistry text requires careful reading comprehension.

The Research

The research will involve completing a survey-questionnaire illustrating a lesson on how you teach the heat concept to your students by:

- Making an audio or video digital recording of your responses to the survey (mandatory)
- Writing down on paper your responses to the survey (optional)

As part of the research I shall try to determine the terminology and concept formation employed by practicing chemistry instructors. This will include:

- The study of any resources used in the classroom
- A textbook analysis

Measures, such as numerical coding, are in please to ensure confidentiality and anonymity. Participants and their institutions' identities will not be revealed for any reason in relation to this research. Students should not be present when digital recordings are made.

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Kelowna, BC Canada V1V 1V7
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www.ubc.ca/okanagan/education

Time Requirement

The entire procedure of completing the survey-questionnaire by digital recording including the optional written component should take approximately one hour. The audio component may be recorded onto a supplied compact disk if desired. Recordings may be sent to the researcher electronically. Any CD and mailing costs will be recovered by the researcher. Please use PC (not Mac); if you do record onto your own PC compatible equipment you will be reimbursed for the cost of the disk. The complete survey-questionnaires may be mailed to the researcher.

Benefits and Risks

Your participation in the study will benefit chemistry teachers/instructors, college faculty members, science education researchers, curriculum developers, textbook writer, and others doing scholarly work in science education in the understanding of the heat concept. Conceptual change perspectives may potentially provide a powerful framework for significantly improving instructional practice.

I do not anticipate any risks in such areas a physical harm, deception, coercion, or conflicts of interest. This is the case because the protocol does not involve physical dimensions, there is no intent to deceive, and participation at all levels is on a voluntary basis.

If you participate in the study all survey-questionnaire answers and audio or video digital recordings produced will be stored in a safe place for a minimum of five years. Only the education committee and the researcher will have access to the data. Computer data will be password protected and printed data will be locked in a cabinet in the researcher's office. Participants and their institutions will be identified only by numerical coding to ensure confidentiality. At the end of the five-year period all collected data will be destroyed, that is, paper shredded, CDs deleted, disks destroyed, and data from electronic files deleted from the database. Participants will be provided with a draft of the study data for comments and feedback.

Your participation is important to me and to the success of my research study. Please do not hesitate to ask questions at any time with respect to your participation the project. I am accessible by telephone or by e-mail (see contact information below). If you would like to participate in this study, please sign the attached letter of consent, and send it to me. If you as a participant in this study have any concern about your rights or treatment as a research subject you may contact the Research Subject Information Line in the UBC Office of Research Services at 604-822-8598 or if long distance e-mail to RSIL@ors.ubc.ca or toll free 1-877-822-8598. Thank you in advance for taking the time to share your teaching skills with me.

Sincerely,

THE UNIVERSITY OF BRITISH COLUMBIA

OKANAGAN

Faculty of Education
3333 University Way
Kelowna, BC Canada V1V 1V7
Tel: 250.807.9176 Fax: 250.807.8084
www.ubc.ca/okanagan/education

Researcher: Donna-Leigh Goodman
Okanagan College
7000 College Way
Vernon, BC
V1B 2N5
dlgoodman@okanagan.bc.ca
(250) 545-7291 local 2258

Supervisor: Dr. Philip Balcaen
University of British Columbia
Faculty of Education
3333 University Way
Kelowna, BC V1V 1V7
philipbalcaen@ubc.ca
(250) 807-8530

Consent Form for Survey Participants

Signing this consent form indicates that I have read the "Information Letter" and understand the purpose of the research study. I have been given the opportunity to ask questions about the study, and these questions were answered to my satisfaction. I understand that my participation is voluntary and that I may withdraw from the study and any time without having to give reasons. I understand that my identity will be kept anonymous. I understand that the data will be maintained in a secure location for a minimum of five years, and that the date will be held until the study is completed; then all data will be destroyed. I understand that the data I provide will not be used for any purpose other than is stated in the letter.

I agree to participate in the study.

Name of participant: ______________________________

Signed: ______________________________

Date: ______________________________

I plan to submit to the researcher:

(a) an audio or video recording ____√_____ (mandatory)
(b) written responses __________ (optional)

Appendix B: Table of Specifications for Survey-Questionnaire

Table 5: Table of Specifications for Survey-Questionnaire

	Question Number
I. Conceptual Framework (Instructor-held Concepts)	1-3
II. Resources Used	4
III. Textbook Analysis	5-9
IV. Demographic Data:	
1. Instructional Setting	10
2. Job Designation	11
V. Educational Qualifications	12-14
VI. Teaching Experience	15

Appendix C: Survey-Questionnaire

An Investigation into the Concept of Heat

Name of Instructor ____
Identification Number ____

Please answer the following questions orally and record your responses either as a digital audio and/or video recording. You may also make a written record of your answers as an option.

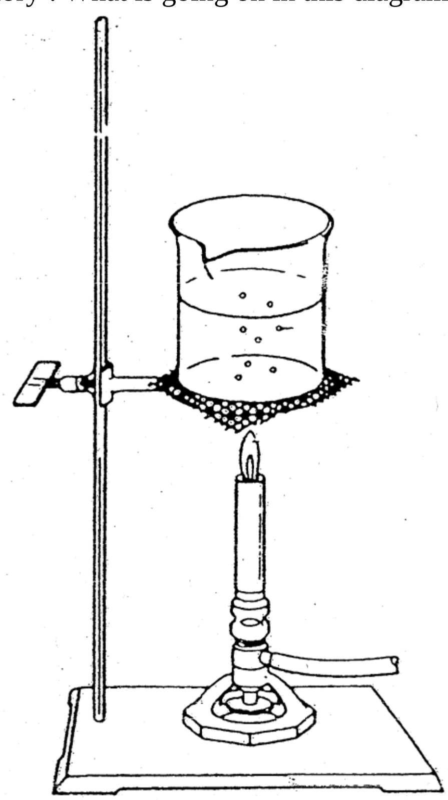
I. Conceptual Framework (Instructor-held Concepts)

1. Briefly explain how you define heat to your class?

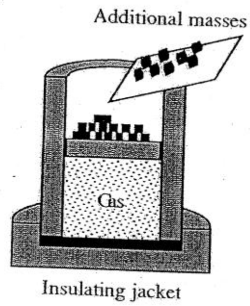
2. How would you teach or motivate a meaningful understanding of heat and temperature to your students?

3. Using the three diagrams provided, explain how you would describe the meaning of each of these pictures as they pertain to chemistry.

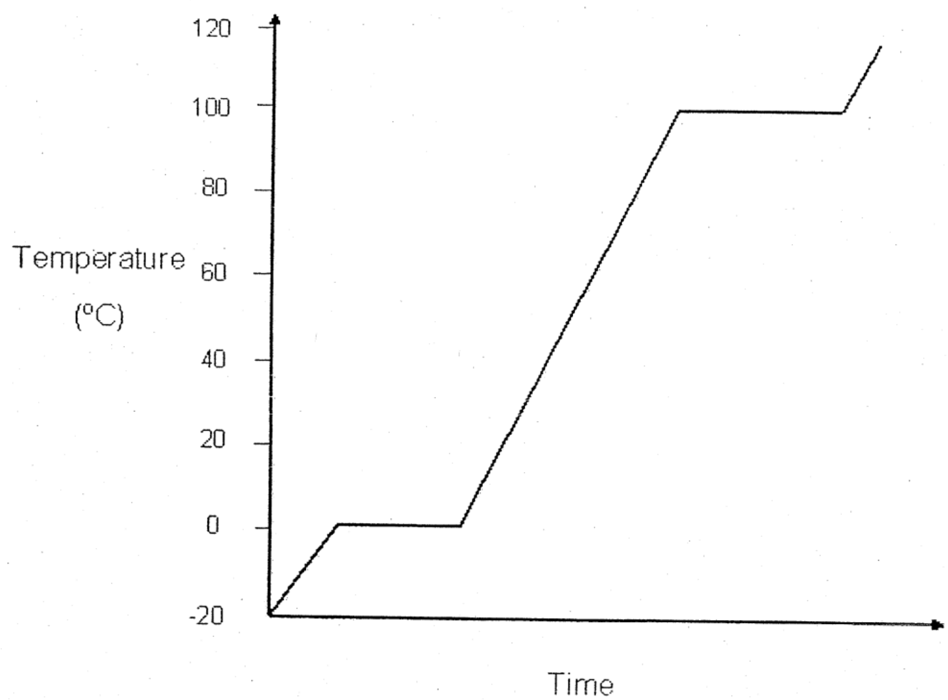
   (a.) The apparatus shown is illustrating pure water being heated in a beaker by a Bunsen burner in a chemistry laboratory[1]. What is going on in this diagram?



(b.) This diagram pictures a cylinder with a frictionless piston containing an ideal gas. The cylinder is placed in an insulating jacket and small masses of the gas are added[2]. As the gas is added how would you explain to your students what will occur with respect to temperature, pressure, and volume of the gas?



(c.) Given this temperature/time graph showing water beginning at a temperature-20°C and being heated until the temperature reaches 100°C (at sea level), explain to your students the meaning of this graph.



II. Resources Used

4. (a.) Concisely describe the specific strategies that you use to aid in your instruction on heat, such as demonstrations or laboratory experiments.

   (b.) List any resources or teaching aids that you employ to teach heat to your class, such as diagrams or models.

III. Textbook Analysis

5. Does the textbook you use in your classroom contain a unit on heat?

6. If so, do you think that the concept of heat is effectively presented?

7. Would you change anything in the textbook’s presented material on heat?

8. If so, explain what you would change?

9. Please specify the chemistry textbook’s Title, Author, Publisher, Date of Publication, and ISBN number.

IV. Demographic Data (Instructional setting and job designation)

10. State the name of the institution at which you are currently employed.

11. List the chemistry courses, with their academic level, that you are currently instructing.

V. Educational Qualifications (Academic Preparation for the Job)

12. (a.) Name the academic degrees you hold.

    (b.) State the title(s) of any theses completed.

13. (a.) What is your academic major?

    (b.) What is your academic minor?

14. How many years of teacher training have you had?

VI. Teaching Experience

15. How many years of teaching experience do you have?

Thank you for participating in this study!

Diagrams courtesy of:

[1]Herron, J.D. (1987). Chapter 1 [test picture, p.2]. In Herron J.D., *Heath Chemistry – Teacher's Resource Binder.* Toronto, Ontario: D.C. Heath and Company.

[2]Kautz, C.H. Heron, P.R.L., Loverude, M.E., & McDermott, L.C. (2005). The insulated-cylinder problem [Figure 3, p. 1057]. In C.H. Kautz, P.R.L. Heron, M.E. Loverude, & L.C. McDermott, *Student understanding of the ideal gas law, part 1: A Macroscopic perspective*. American Journal of Physics, 73(11).

Appendix D: Textbook List for Analysis

Gilbert, T. R., Kirss, R. V., Foster, N., & Davies, G. (2009). *Chemistry.* (second edition) New York: W. W. Norton & Company, Inc. ISBN: 978-0-393-92649-1

Hebden, J. A. (1998). *Chemistry 11 – A workbook for students.* Kamloops, B.C.: Hebden Home Publishing. ISBN: 0-9682069-1-3

Hebden, J. A. (1998). *Chemistry 12 – A workbook for students.* Kamloops, B.C.: Hebden Home Publishing. ISBN: 0-9682069-0-5

Herron, J. D., Kukla, D. A., Schrader, C. L., Morrison, D., DiSpezio, M. A., Erickson, J. L., & Scodellaro, D. (1987). *Chemistry.* (Canadian edition) Canada: D. C. Heath Ltd. ISBN: 0-669-95289-3

Petrucci, R. H., Herring, F. G., Madura, J. D., Bissonnette, C. (2011). *General chemistry: Principles and modern applications* (10th edition). Toronto, Ontario: Prentice – Hall, Inc. ISBN: 978-0-13-206452-1

Wilbraham, A. C., Staley, D. D., Matta, M. S., Waterman, E. L. (2008). *Chemistry.* New Jersey: Pearson Prentice Hall. ISBN: 0-13-251210-6

Zumdahl, S. S. (1996). *Introductory chemistry: A foundation* (3rd edition). Lexington, MA./Toronto: D. C. Heath and Company. ISBN: 0-669-39761-X

Zumdahl, S. S., & DeCoste, D. J. (2011). *Introductory chemistry: A foundation* (7th edition). U.S.A.: Brooks/Cole, Cengage Learning. ISBN-13: 978-1-4390-2