INTERNATIONAL STUDENTS' EPISTEMOLOGIES AND LEARNING EXPERIENCES IN SPECIALLY DESIGNED FIRST-YEAR CHEMISTRY COURSES

by

Priya Anka Lekhi

B.Sc., The University of British Columbia, 2003

M.Sc., The University of British Columbia, 2006

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The following individuals certify that they have read, and recommend to the Faculty of Graduate and Postdoctoral Studies for acceptance, the dissertation entitled:

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in Curriculum Studies

Examining Committee:

Dr. Marina Milner-Bolotin
Co-supervisor

Dr. Samson Nashon
Co-supervisor

Dr. Douglas Adler
Supervisory Committee Member

Dr. James Anderson
University Examiner

Dr. Cynthia Nicol
University Examiner

Dr. Guoqiang (George) Zhou
External Examiner

Additional Supervisory Committee Members:

Supervisory Committee Member

Supervisory Committee Member

Abstract

First-year university science courses are often challenging for a majority of students coming out of high school, with international students having even greater adjustment difficulties. This may be due to differences between the epistemologies held by the students and the epistemological expectations of the science courses. Active learning environments have different epistemological expectations than traditional lectures and international students may have inadequate prior experiences with this mode of learning science. Thus, an exploratory case study approach to investigate first-year international students' epistemologies and experiences in their chemistry courses within the Vantage One Science Program was conducted. Vantage One Programs, which reside in Vantage College at the University of British Columbia, admits and offers first-year programs to international students from non-English speaking countries. The case study largely employed a mixed methods methodology that used both quantitative and qualitative tools for data collection. To assess the students' epistemologies, the Epistemological Beliefs about Physical Sciences (EBAPS) instrument was administered three times during the program. The three data sets were analyzed using exploratory and confirmatory factor analysis to determine dominant factors underlying the students' responses to the items on the EBAPS, interpreted as a description of the key student epistemologies. Student grades from CHEM 121 and CHEM 123 courses were also collected and correlated with scores from the EBAPS questionnaire. Qualitative methods were used to examine students' epistemologies and their views on their experiences. These methods included classroom observations, one-on-one semi-structured and task-based interviews and focus group interviews. The results indicate that some aspects of student epistemologies transformed over the course of the first year Vantage program while others aspects remained the same. When factors did transform, they transformed towards

more canonical epistemologies. Transformations included valuing peers and oneself as a source of science knowledge and becoming more aware of the nature of science. Some of these transformations can be attributed to the pedagogy experienced in Vantage One Science Program, including the use of peer-learning pedagogy and inquiry-based learning. Both qualitative and quantitative data suggest that more canonical views are associated with positive study approaches, problem-solving strategies, and academic performance.

Lay Summary

This study explored first-year international student science knowledge views and their experiences in active learning environments of two chemistry courses at the University of British Columbia (UBC). Students completed the Epistemological Beliefs about Physical Sciences (EBAPS) instrument to assess their epistemologies during the year. They were also observed and interviewed at select times during the year. All data collected including student grades were analyzed. The results indicate that aspects of student views of scientific knowledge did transform into views more aligned with the tenets of science while other aspects remained the same. Some of the transformations in views can be attributed to the learning environment fostered in the first-year chemistry courses. Views aligned with canonical science beliefs tended to manifest better academic performance, engagement in active learning environments, and the use of more effective study strategies.

Preface

This dissertation is original, unpublished, independent work by the author, Lekhi, P. The research was designed, carried out, and analyzed by Lekhi, P. with support from Drs. Samson Nashon, Marina Milner-Bolotin, and Douglas Adler.

This research study obtained the approval of the UBC Research Ethics Board (Behavioural Research Ethics Board; UBC BREB Number: (H14-02058).

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Dedication

I dedicate this thesis to my parents, Chander and Veena Lekhi, my husband, Ram Pratap Siddha and my kids, Aryan and Simran. You all helped to motivate me when I wanted to give up. I hope this dissertation makes you proud!

Chapter 1: Introduction to the Study

1.1 Introduction

The University of British Columbia (UBC) is an internationally renowned university with a first-year undergraduate program that enrolls 2000+ domestic and international students into General Chemistry courses. In 2015/2016, the international students at UBC were citizens from over 150 countries, where the most common countries of citizenship were China, United States of America (USA), South Korea, India, and Japan (Szeri & Mathieson, 2018). Prior to coming to UBC, first-year international students studied in schools with a range of curricula, pedagogies, and graduating requirements ("International High Schools UBC Admission Requirements," 2018).

Upon arriving at UBC, first-year students may experience courses with an active learning component and/or focus on critical thinking. One of the most agreed upon goals of higher education is to develop students' critical thinking skills (Baxter Magolda, 2003). Critical thinking is using reason to make your decisions and having the ability to examine beliefs and/or knowledge (Glaser, 1995). Critical thinking is about not accepting knowledge as a set of rules or facts without reflecting as to why they take place (Glaser, 1995). In an attempt to encourage critical thinking in science, UBC created the Carl Wieman Science Education Initiative, to transform a lecture-based approach to one focused on active learning through the adoption of teaching methods such as peer instruction, group work, and in-class problem solving (Deslauriers, Schelew, & Wieman, 2011; Fox et al., 2014; Mazur, 2009; Wieman, Perkins, & Gilbert, 2010). The Carl Wieman Science Education Initiative has had positive impacts on student attendance, engagement, and learning (Deslauriers et al., 2011). As universities strive to promote independent critical thinking, group work, and problem solving, incorporating active learning techniques to facilitate the development of these skills (Baxter Magolda, 2006; Biggs & Tang, 2007; Fox et al., 2014; Wieman, 2012), there is an assumption that students are ready to develop these skills coming out of high school.

However, students entering first-year science courses can find university coursework difficult which has led to high attrition rates (Kalman et al., 2014; Parkin & Baldwin, 2009). Research indicates that international students have even greater adjustment difficulties, and they experience more stress and anxiety when compared to domestic students (Andrade, 2006). For example, studies suggest that international students experience feelings of isolation and homesickness (Kwon, 2009). Added to these stresses, the majority of international students at English-speaking universities report that the most common mode of instruction in their homelands is the lecture (Andrade, 2006); hence pedagogical strategies which emphasize active learning may disadvantage many international students (Smith & Khawaja, 2011). Indeed, Liberman (1994) reported that Asian students studying in the USA stated they found it difficult to adjust to the interactive style and critical thinking approach to learning. More recently, Chinese international students studying in Canada reported challenges when actively participating in group work and learner-centered classroom environments (Zhang & Zhou, 2010). In another study, some Chinese students were reported to view American classrooms as lacking structures and proper behaviours from both teachers and students rather than being interactive, flexible, informal, and creative (Wan, 2001). International students also reported they found courses which emphasized applications to be challenging because they were accustomed to coursework with a focus on theoretical knowledge (Zhou & Zhang, 2014).

How students engage in classroom activities, such as those emphasizing active learning, has been shown to be related to students' personal epistemological beliefs: "…student [epistemological] beliefs affect their involvement with particular tasks or in particular instructional settings" (Hofer, 2001, p. 373). Epistemological beliefs are beliefs about what constitutes knowledge and how one comes to know (Hofer, 2004). Thus, challenges students face may be related to the differences between their epistemologies and the epistemological expectations of first-year science courses. In general, first-year university students hold less informed epistemological views (Abd-El-Khalick, 2006; Hofer, 2004b; Schommer, 1993a; Tsai, 1999) as they view knowledge as dualistic (right or wrong answers) and look towards an external authority such as a textbook or an instructor as the holder of knowledge. Thus, important goals in undergraduate education are epistemic in nature because critical thinking involves a transformation in viewing the certainty, source, and limitations of knowledge (Baxter Magolda, 2006). For example, critical thinking involves shifting away from an external authority that validates one's own knowing to reliance upon one's own inner ways of knowing (Baxter Magolda, 1992). Students with less informed epistemologies find it difficult navigating college (Walker et al., 2009); high attrition rates in first-year science students may be related to the gap between a student's current epistemology and the epistemological expectations of university (Daempfle, 2003). For example, students in an active learning environment may be expected to rely more on their own way of knowing whereas students in a traditional lecture may be expected to rely more on an external authority for knowledge. Experiencing educational expectations that differ from one's current epistemology can be stressful and challenging for any student but is likely more intense for international students compared to domestic students because of potentially having fewer active learning classroom experiences to draw upon (Andrade, 2006; Huang, 2012; Pratt, Kelly, & Wong, 1999a; Yi Zhang, 2016).

1.2 Context

The Vantage One Science Program at UBC Vantage College offers an 11-month program taught by UBC Faculty for first year international students. Vantage One Science Program is only open to international students (Canadian citizens or permanent residents of Canada are ineligible for admission) and to students who require additional academic English instruction as they begin their UBC degree. The program begins in September and ends in July of the following year. Class sizes are relatively small (< 50), and courses in the program use alternative teaching methods to traditional lecturing ("UBC Vantage College," 2017). The focus of this study was the epistemologies of first-year students in the Vantage One Science Program at the start of the program, and how the epistemologies were affected by participating in first-year chemistry courses. First-year chemistry is divided into CHEM 121 (General Chemistry), which was taught in September-December 2015 (Term 1), and CHEM 123 (Physical and Organic Chemistry), which was taught from May-July 2016 (Term 3).

1.3 Problem Statement

Students entering first-year science courses can find university challenging due to conflicting epistemological positions. International students may have more intense difficulties in an active learning environment because they potentially have fewer active learning classroom experiences (Andrade, 2006; Pratt, Kelly, & Wong, 1999b; Zhou & Zhang, 2014). Despite the large international population in first-year chemistry and the pedagogical innovations in science courses at UBC, there is a lack of literature in the field on studies that have focused on the understanding of connections between epistemology, high school and university experiences, and pedagogy. This lack of understanding may be resulting in a deficiency of support for students or poor pedagogical decisions by university instructors. To address this problem, this study explored student epistemologies with respect to first-year chemistry courses within the Vantage One Science Program and how these epistemologies transformed over the 11-month program. In addition, the study explored the relationships, if any, between student epistemologies and their experiences in the context of first-year chemistry.

1.4 Research Questions

This study was guided by the following research questions:

1. What personal epistemologies are evident among first-year international UBC Vantage College undergraduate students in the Vantage One Science Program at the beginning and the end of Chemistry 121 and Chemistry 123?
2. How are these personal epistemologies affected over the 11 month period in the program?
3. How are these personal epistemologies implicated in student academic performance, study approaches and views of pedagogy used in first-year chemistry?

1.5 Significance of the Study

This study provides insights into a cohort of first year international science students' epistemologies and how their epistemologies evolved during their participation in the Vantage One Science Program. The study investigates relationships between student epistemology, pedagogy, and academic performance that can assist educators with course design, instruction, and assessment. This study involves international students who require additional academic English instruction and can offer additional insight into the academic challenges faced by international students in Canadian universities.

1.6 Organization of the Thesis

This dissertation is organized into seven chapters. Chapter 1 presents the introduction to the study, problem statement, research questions, and the study's significance. Chapter 2 presents a literature review of three models of personal epistemology, defines how epistemology will be used in this thesis, explores how the literature describes less informed and informed epistemologies in science, relates student epistemology to learning and engagement with science, examines undergraduate student epistemology in science, and explores how pedagogy can promote epistemological development. Chapter 2 concludes with a discussion of the three pedagogies used in Vantage One Science first-year chemistry. Chapter 3 describes the study context and participants and also discusses the methodology and details of the methods used to collect and analyze data in order to answer the research questions followed by comments on the study's ethical considerations and limitations. Chapter 3 concludes with a timeline of data collection and the methods used to analyze the data. Chapter 4 focuses on the quantitative data analysis from which dominant/principal epistemology aspects or factors were determined, evaluated, and interpreted followed by correlation analysis. Chapter 5 presents a thematic analysis of the qualitative data and Chapter 6 presents a discussion of the correspondence between the key findings determined from the quantitative data and the emergent themes from the analysis of the qualitative data. Chapter 7 provides the conclusions, limitations and suggestions of areas for further research.

Chapter 2: Literature Review

In this chapter, I provide an overview of studies about epistemologies and include a discussion of three relevant models characterizing the reviewed studies. I then define how epistemology is used in this thesis and follow with an exploration of how epistemologies are characterized and then discuss the effect of personal epistemology on learning. The second half of the chapter examines undergraduate student epistemologies in science and the role of pedagogy in promoting epistemological growth. Finally, I discuss three specific pedagogies implemented in first-year chemistry courses in the Vantage One Science Program.

2.1 Epistemology

Epistemology as defined by Steup (2017) is the study of knowledge and justified beliefs which involves issues related to the creation and dissemination of knowledge in particular areas of inquiry. The study of student epistemologies has become a growing area of interest for educators. Researchers in this area use a range of terms including: epistemological beliefs (Schommer, 1990); epistemological theories (Hofer & Pintrich, 1997); reflective judgment (King & Kitchener, 1994); epistemological reflection (Baxter Magolda, 1992); and epistemological resources (Louca, Elby, Hammer, & Kagey, 2004). These terms are part of a larger body of research categorized as "personal epistemology" (Hofer & Pintrich, 2002). The field of "personal epistemology" examines what learners believe about how knowing occurs, what counts as knowledge, where knowledge resides, how knowledge is constructed, and how knowledge is evaluated (Hofer, 2004). Some researchers also include beliefs about learning under the umbrella of personal epistemology (Elby, 2009; Schommer-Aikins & Easter, 2006). My review of the literature revealed that researchers have conceptualized personal epistemology in multiple ways. I will now discuss three models of epistemology.

2.2 Epistemological Models

Personal epistemology has origins in cognitive psychology (Perry, 1970). A number of models describe personal epistemology and its development. One model of personal epistemology approaches epistemology as a cognitive development process that proceeds in a patterned, one-dimensional, developmental sequence (Baxter Magolda, 1992; Belenky, Clinchy, Goldberger, & Tarule, 1985; D. Kuhn, Cheney, & Weinstock, 2000; Perry, 1970). A second model presents personal epistemology as a multi-dimensional system of independent beliefs (Hofer, 2000; Schommer, 1990; C. Tsai, 1997). A third model characterizes personal epistemology as context-dependent (Hammer & Elby, 2002) where cognitive resources are activated depending on context and are then engaged during the process of learning. I will now discuss these models beginning with the epistemological development models.

2.2.1 Epistemological Development Models

William Perry's (1970) work is identified throughout the literature as the beginning of personal epistemology research. In fact, "nearly all the existing psychological work on epistemological beliefs and theories can be traced to two longitudinal studies by Perry" (Hofer, 2000 p. 379). Perry interviewed male students at Harvard during the 1950s and 60s during their 4-year degrees to document their views of knowledge. He proposed the Perry Scheme where college students pass through a predictable sequence of positions of epistemological growth (Perry, 1970). Perry's analysis of the interview data led to an epistemological development model that consisted of nine positions (Hofer & Pintrich, 1997). In the Perry Scheme, there is a single progression or dimension from dualist to relativist epistemologies. The first and most naïve position is a dualistic or absolutist view of knowledge where students identified knowledge as simply wrong or right. The higher positions are where the student begins to acknowledge that there is uncertainty in knowledge and there are multiple perspectives. The final position is a more constructivist-oriented position where students see themselves as contributors to knowledge, and the role of evidence and justification are recognized. Since his work, further research on epistemological beliefs and reasoning has refined, extended and adapted Perry's developmental sequence (Hofer & Pintrich, 1997).

Perry's model named, "Perry's Scheme" is a framework for analyzing the epistemological beliefs of a female sample that included university students as well as social service clients (Belenky et al., 1985). The result was a developmental stage theory similar to Perry's, but this model described the positions in terms of the knower. Marcia Baxter Magolda in 1992, building on the work of both Perry (1970) and Belenky et al. (1985), aimed to explore a "gender-inclusive model of epistemological development" (Baxter Magolda, 2004, p. 91). The research was based on a longitudinal interview study beginning with a gender-balanced sample of college freshmen followed into adulthood which resulted in the Epistemological Reflection Model. Baxter Magolda identified four knowledge stages describing the various levels of reasoning characterized in the Epistemological Reflection Model: absolute knowing; transitional knowing; independent knowing; and contextual knowing. College students may be identified at any of the four knowledge stages of this model. Baxter Magolda discerned that both genders followed the same basic developmental sequence, but she also found subtle gender differences, such as reasoning patterns, within early developmental stages that seemed to dissipate as students progressed beyond college.

In the 1980s, King and Kitchener (1994) developed and validated a model of learner development of reflective judgment from late adolescence through adulthood. The Reflective Judgment Model indicates how the learner evaluates knowledge claims and justifies beliefs about arguable issues (King & Kitchener, 2004). The model's levels are constructed from John Dewey's work on reflective thinking and closely parallel the first six levels of Perry's (1970) model. The model shows a progression in the development of reflective thinking leading to the ability to make reflective judgments in seven stages within three levels. Each stage represents a qualitatively different epistemological perspective. The seven stages are grouped into three levels and include pre- reflective thinking (stages 1-3), quasi-reflective thinking (stages 4-5), and reflective thinking (stages 6-7).

2.2.2 Multi-Dimensional Models

Schommer's (1990) multi-dimensional theory of epistemological beliefs was a shift in epistemological research. Instead of a developmental sequence, Schommer's theory characterized epistemological beliefs as a set of "more or less" *independent* dimensions. In a multi-dimensional model, a student could hold naïve views of one dimension of epistemology while holding a more informed view of a different dimension of epistemology. Her theory consisted of five epistemological dimensions based on previous research that addressed the certainty, simplicity, and source of knowledge, and the control and speed of knowledge acquisition. The first of Schommer's (1990) hypothesized dimensions, certainty of knowledge, describes a continuum that ranges from a naïve view of knowledge as absolute truth to a view that knowledge is tentative and evolving. A second hypothesized dimension is the simplicity or structure of knowledge that reflects a continuum ranging from understanding knowledge as isolated bits to an understanding of knowledge as interrelated concepts. The third dimension is labeled as a source of knowledge. This dimension reflects a range of views regarding the role of an authority figure. The naïve view is the belief that knowledge is external to the learner, and thus knowledge must be obtained from an authority. The more sophisticated view reflects a constructivist understanding of the learning process as an interactive event with the learner functioning as an active participant in the creation of knowledge rather than a passive recipient. The fourth hypothesized dimension, control of knowledge acquisition, was derived from research in theories of intelligence. The essence of this dimension is whether people hold a fixed view of intelligence leading Schommer (1990) to name this dimension innate ability. A person with a fixed or naïve view of innate ability generally takes a deterministic view of intelligence and would endorse the idea that you have only what you are born with and no more. The person with a more sophisticated view of innate ability believes that intelligence functions more like a skill that can be improved with effort. A fifth and final dimension is speed of knowledge acquisition. This belief ranges from the naïve view that learning happens quickly or not at all to the more sophisticated view that learning is a gradual process that requires continued effort and persistence (Schommer, 1990).

Barbara Hofer (2000) produced a similar multi-dimensional theory from an extensive analysis of existing theories (Hofer & Pintrich, 1997). However, Hofer's model labels these conceptualizations as epistemological theories, rather than beliefs (2000). In Hofer's model, there is integration among an individual's perspective rather than a collection of independent beliefs. Hofer and Pintrich (1997) echoed three of Schommer's dimensions in their model (certainty, simplicity of knowledge, and source of knowledge). Hofer, (2000) added a fourth dimension: justification for knowing, which references "how individuals evaluate knowledge claims, including the use of evidence, the use they make of authority and expertise, and their evaluation of experts" (p. 381). Hofer (2000) dismisses two of Schommer's dimensions, innate ability and speed of acquisition of knowledge, because, in her view, they are more related to intelligence rather than epistemology. Hofer and Pintrich (1997) present a broader construct in which their four dimensions are embedded: nature of knowledge, which includes dimensions of the certainty and simplicity of knowledge, and the process of knowledge, which includes dimensions of source of knowledge and justification for knowing.

2.2.3 Epistemological Resources Model

Hammer and Elby (2002) proposed epistemological resources as an alternate model for personal epistemology. Their view is that personal epistemology is more context specific and less stable than what is represented in other models of epistemology. Consider Schommer's hypothesized dimension, source of knowledge, which describes a continuum from understanding knowledge as handed down by authorities to knowledge being constructed by the learner. Elby (2001) argued that it is more likely that a learner can hold both views simultaneously and engage one or the other depending on context. For example, a student may rely on an authority, such as an instructor to provide strategies for solving a chemistry problem but simultaneously believe that understanding will only come by working through problems independently. Thus, the complexity of this student's epistemological framework could not be assessed with a generic question regarding the role of authority in transmitting knowledge; context is essential. In the epistemological resources model, students' epistemologies are described as “fine-grained cognitive resources whose activation depends on context” (Elby & Hammer, 2001).

2.3 “Epistemology” as Used in this Thesis

This thesis is largely informed by the work of Hofer, Schrommer, and Hammer and Elby. Hofer (2004) categorizes research in “personal epistemology” as examining what learners believe about how knowing occurs, what counts as knowledge, where knowledge resides, how knowledge is constructed, and how knowledge is evaluated. Hammer and Elby (2002), building on the work of Hofer and Pintrich (1997) and Schommer (1990), view epistemology as multi-dimensional but further understand personal epistemology as context-specific and malleable. Following Elby (2009), I will include beliefs about learning under the category of personal epistemology. Thus, in this thesis, “personal epistemology” or simply, “epistemology” refers to the student’s beliefs (whether explicit or tacit) about knowledge and learning. Epistemology is viewed as multi-dimensional, context-specific, and malleable.

2.4 Informed Epistemology in Science

Epistemological beliefs about science are referred to as scientific epistemological beliefs (Liu & Tsai, 2008). Consider the following two questions: "How is knowledge created in science? What is scientific knowledge?” The answers to these questions comprise an individual's science epistemological beliefs (SEB) (Deng, Tsai, & Chai, 2011). Deng et al. (2011) consider positivist views as naïve and constructivist views as sophisticated. Positivism is a broader philosophy that reality is external to the individual and there is a single truth. A positivist epistemology in science would be that knowledge in science is completely objective and external to the knower (Posner, 2004). The epistemology of constructivism involves two key pieces; the first is that knowledge is constructed by a thinking person, not passively received and second, “coming to know is an adaptive process that organizes one's experiential world; it does not discover an independent, pre-existing world outside the mind of the knower” (Matthews, 1993, p. 363). More than an epistemology, constructivism is an underlying philosophy or way of seeing the world. This way of seeing the world includes notions about: The nature of reality (an individual’s view of the world is as real as the "world out there"); The nature of knowledge (it is individually constructed and not “out there"); The nature of human interaction (we rely on shared meanings) (Cakir, 2008). For a constructivist, science is a meaning-making activity with the biases and filters accompanying any human activity (Cakir, 2008). Historically, there has been a revolt against positivist theories of science, as reflected in the work by Thomas Kuhn and Leon Lederman. Kuhn (1962) argued that the possibility of impartial knowledge free from theoretical assumptions was not possible and that scientists were influenced by the theoretical assumptions of the current paradigm. Lederman argued for a constructivist-oriented epistemology of science highlighted by the human-constructed, sociocultural embedded and tentative nature of scientific knowledge (Khishfe & Lederman, 2007). Conversely, Hammer and Elby (2002) argue for a re-examination of what is considered as informed or sophisticated epistemology and the role of context: “It is hardly sophisticated, for example, to consider it ‘tentative’ that the earth is round, that the heart pumps blood, or that living organisms evolve” (p. 186). Thus, there must be an acknowledgment of the role of evidence and consensus in the development of scientific knowledge.

2.5 Effect of Personal Epistemology on Learning

How students interact with classroom activities has been shown to be related to their personal epistemological beliefs: "…student [epistemological] beliefs affect their involvement with particular tasks or in particular instructional settings" (Hofer, 2001, p. 373). For example, those students whose beliefs about knowledge understand the source of knowledge as being from an authority such as a professor or a textbook will struggle with activities such as independent research where they themselves are the source of knowledge. In this section, I will summarize the research on the effect of student epistemology in science on student learning and engagement.

Many studies have focused on the relationship between scientific epistemological beliefs and learning approaches (Cano, 2005; Saunders, 1998; Tsai, 1997). For example, students who believe that knowledge comes from an external authority are more likely to attempt to memorize the information than to try to make sense of the information themselves (Saunders, 1998). Also, students who have adopted an informed (or constructivist) epistemology are more likely to engage in meaningful learning such as discussions with others, concept mapping and problem solving (Cakir, 2008). Edmondson and Novak (1993) determined that students who identified as logical positivists tended to be rote learners and more grade-oriented, whereas those identified as constructivists used meaningful learning strategies as the primary goal to understanding material. Furthermore, students with constructivist epistemology emphasized the importance of true conceptual understanding, whereas students with more naïve epistemologies emphasized more problem solving practices and to listen the teacher carefully in the class for success in learning science (Tsai, 1997). Two years later Tsai, (1999) found that students having constructivist epistemological beliefs engaged in more active learning, whereas other students tended to use more rote learning strategies because they believed science to be a collection of facts. The relationship between student epistemological beliefs in science and student perceptions of their learning environments was investigated by Tsai (2000) in a study of 1283 Taiwanese tenth graders in Northern, Central and Southern Taiwan. Students having epistemologies more oriented to constructivist views of science tended to perceive that their actual learning environments did not offer adequate opportunities for them to negotiate their ideas nor integrate new information with their prior knowledge. Additionally, findings indicated participants preferred to learn in constructivist environments where they could interact with others, integrate their prior knowledge and experiences with new constructed knowledge and have control of their learning activities.

Studies have also linked scientific epistemology to a student's motivation for learning science. For example, a study of undergraduate science students in Taiwan found that when they believed scientific knowledge to be an evolving and changing subject and that scientific knowledge comes from reasoning, thinking, and experimenting, students expressed a strong desire to truly understand the scientific knowledge, and to be meaningfully engaged in the process of scientific inquiry. Thus, these students' science learning would be intrinsically motivated (Liang, Lee, & Tsai, 2010). Similarly, Kizilgunes, Tekkaya, and Sungur (2009) found that students with sophisticated beliefs about the development and justification of knowledge tended to have a strong desire to learn for the purpose of understanding. These findings aligned with Tsai's (1997) findings where students with more naïve epistemology were found to have learning goals more oriented to course grades than real understanding. On the other hand, students with more sophisticated epistemology were mainly motivated by their interest and desire to understand more (Tsai, 1997). Buehl and Alexander, (2005) reported that students with more sophisticated beliefs had higher levels of motivation for task performance in mathematics and history. This claim was corroborated in a physics context; Lising and Elby (2005) found that physics students' learning was significantly related to their perceptions about the nature of physics, physics learning, and knowledge. Student attitudes towards science were positively affected by more favorable epistemology (Tsai, 2000). For example, an unfavourable epistemology views science as a collection of unrelated facts and more likely to lead to a negative attitude about science because there is less opportunity for the learner to interact with fact-based scientific knowledge (Tsai, 2000).

Another area of research includes linking epistemology with academic success as students who hold certain epistemological views are more likely to achieve higher academic success (Schommer-Aikins & Easter, 2006). Walker et al. (2009) argue that students who do not believe knowledge can be created through independent learning may experience difficulty navigating through higher education. According to Palmer and Marra, (2004), science majors who view science as a collection of facts have trouble understanding the instructor's use of evidence as the basis of judgments or decisions and are essentially incapable of gathering and using evidence for their own judgments. Stathopoulou and Vosniadou, (2007) found that students with sophisticated epistemologies achieved deeper understanding of Newton's Laws as compared to those with naïve epistemological beliefs.

Finally, student epistemology has also been linked to metacognition. Metacognition is active monitoring and regulation of the learning process (Anderson & Nashon, 2007). In a qualitative study of nine students in first-year General Chemistry, researchers found that students exhibiting naive epistemology resorted to simplistic ways of acquiring knowledge and demonstrated low metacognitive behaviours; whereas students who manifested sophisticated epistemology selected study strategies for understanding, were more engaged in their learning, and overtly demonstrated high metacognitive behaviors (Pulmones, 2010).

2.6 Undergraduate Student Epistemology in Science

Research indicates that students entering first- year university tend to have less informed epistemologies (Baxter Magolda, 2006; Felder & Brent, 2004a; Perry, 1970). The following is a summary of studies on epistemologies of students enrolled in introductory science university-level courses. Many learners enter college at the level of absolute knowing, believing that knowledge is certain, authorities have the knowledge and the responsibility to communicate that knowledge, while the learners' job is to absorb and repeat knowledge (Baxter Magolda, 1992; Felder & Brent, 2004a). Gilbert (1991) used 12 statements to assess the views of undergraduate college students enrolled in an introductory biology course and found 67% of participants held the naïve view that scientific knowledge depicts the "reality" of nature. Ibrahim, Buffler, and Lubben (2009) studied the views of first-year Physics students and found that 47% of the students studied described scientific knowledge as behavioural in nature. Only 30% described scientific knowledge as based on experimental evidence. Fleming (1988), and in a later study Abd-El-Khalick (2006), assessed undergraduate chemistry students and reported that participant undergraduate students' conceptions of the development and evaluation of science knowledge were very similar to the naïve conceptions held by high school students. A study by Jehng, Johnson, and Anderson (1993) showed that science learners are more likely than learners in social sciences and humanities to believe in the certainty of knowledge and in an authority as the source. In their investigation of the epistemological views of male, college-bound physics students, Roth and Roychoudhury (1994) concluded that "two thirds of the students were committed to the view that scientific knowledge is exact, not tentative, and that it is independent of conceptualization" (p. 27). Lastly, a mixed-mode study of 166 undergraduate science students who were interviewed and completed a questionnaire, found 90% of the participants had views that scientific knowledge was unchanging and factual, and they failed to recognize the role of scientific theories in guiding research (Abd-El-Khalick & Lederman, 2000).

2.7 Epistemological Development and Pedagogy

Research suggests that education can influence epistemological development (Perry, 1970; Schommer, 1993b) specifically in teaching and learning contexts that expose the learner to a variety of educational viewpoints. The progression of post-secondary students’ epistemology from freshman (first-year or year one) to senior years is well supported using Perry’s and the Reflective Judgment Model (King & Kitchener, 2004). On average, the learner enters undergraduate post-secondary education at the level of pre-reflective thinking (dualism in Perry’s model). They base their judgments on unconfirmed beliefs, and the declaration of authorities, and leave post-secondary undergraduate education at the quasi-reflective thinking level (multiplicity), beginning to seek, and use evidence to support their judgments. Studies indicate very few graduates reach the level of reflective thinking (contextual relativism in Perry’s model). Researchers using the Reflective Judgement Model found that only advanced doctoral students were consistently able to reason reflectively (Felder & Brent, 2004). Exposure to advanced education and life experiences may cause cognitive conflict that results in the reconstruction of naïve epistemological beliefs into more relativistic, sophisticated beliefs about knowing (Belenky et al., 1985; Schommer, 1998). However, other studies suggest that the realization of a sophisticated critically aware view towards knowledge is rare even in adulthood (King & Kitchener, 1994; Kuhn et al., 2000).

There is evidence that selective educational practices influence the development of students' epistemological beliefs (Baxter Magolda, 1992; Hofer, 2004; Schraw, 2001). Change in epistemological beliefs takes place when learners are challenged to reconstruct naïve beliefs into more sophisticated ways of knowing (Hofer & Pintrich, 1997). To target students' epistemological beliefs, educational practices should provide students with the challenge, reflection, and support needed to promote epistemological development. Recommendations for classroom environments that enhance development across epistemological positions have included encouraging learner questions and comments, instructor recognition of learner reactions, and increased emphasis on learner participation (Baxter Magolda, 1992; Felder & Brent, 2004). King and Kitchener (2004) recommend providing opportunities for learners to discuss and analyze ill-structured problems and develop skills related to gathering and evaluating data. The authors also advise engaging learners in the discussion of controversial issues and assisting them in examining their assumptions about knowledge and how knowledge is gained. Numerous studies suggest involving individual students in learning tasks and in groups that require them to take more responsibility for their own learning (Felder & Brent, 2004; Hammer & Elby, 2003; Herron & Nurrenbern, 1999; Hogan & Maglienti, 2001).

Samarapungavan et al., (2006) found that students' epistemologies varied significantly with exposure to authentic research in chemistry. Those who participated in research activities evaluated and conceptualized science and scientific knowledge very differently from undergraduate and high-school students enrolled in traditional chemistry courses. For example, when asked an open-ended question to describe science, those who participated in chemistry research were more likely to mention standard procedures for gathering evidence and standards for evaluating scientific claims such as replication. Students who did not participate in chemistry research, described science in simpler terms, specifically as a way to understand nature, and they did not articulate any criteria for evaluating scientific knowledge (Samarapungavan, Westby, & Bodner, 2006). Progressing from a more structured, "cookbook" laboratory environment to one of less structure and more inquiry focused can encourage personal epistemological growth (Mazzarone & Grove, 2013). Finally, Hofer (2001) asserts that epistemological development may be fostered by methods that validate the learner as a knower, situate learning within the learner's experience, and create chances for learners to construct meaning with others. This is in line with an underlying constructivist approach to teaching. This approach translates into teaching methods and activities that focus on a student's prior knowledge because the students are organizing new knowledge with their own experiences, on inquiry-based methods as students are discovering the knowledge themselves rather than being told through lectures, and peer-based activities because knowledge is socially constructed (Matthews, 1997).

2.8 Pedagogies Used in Vantage One Science First-year Chemistry

The first-year chemistry courses in the Vantage One Science Program promote active learning. Active learning is defined as any instructional method that includes student activity in the classroom and student engagement in the learning process and is in contrast to traditional lecturing where students passively receive information from the instructor (Prince, 2004). I will now discuss the three pedagogies used in the first year chemistry courses in the Vantage Once Science Program: (1) Partial flipped classroom (CHEM 121 Lecture); (2) Peer Instruction (CHEM 123 Lecture); and (3) guided inquiry-based learning (CHEM 121/123 Laboratory). Specific details of each course are discussed in Chapter 3 Sections 3.1.4 to 3.1.6.

2.8.1 Partial Flipped Classroom

The flipped classroom consists of three elements: (1) individual instruction outside of the classroom that takes place before the topic is discussed (pre-class material); (2) peer-based problem-solving inside the classroom; and (3) assessments that enable students to evaluate their level of understanding (Bishop & Verleger, 2013; Persky & McLaughlin, 2017; Seery, 2015). In a flipped classroom, the instructor does not provide a summary of pre-class material during class. In a partially flipped classroom, a small portion of the class time (< 20% of class time) is spent on summary lectures at the start of class where the instructor can highlight difficult concepts from the pre-class material (Lax, Morris, & Kolber, 2017). The rest of the pre-, in-, and post-class material in a partial flipped classroom follows a flipped classroom approach. The following is a discussion of the underlying theoretical framework of a partial flipped classroom and flipped classroom approach.

The flipped classroom pedagogical approach draws upon a constructivist approach stemming from the learning theories of Jean Piaget and Lev Vygotsky (Bishop & Verleger, 2013). In Piaget's theory of intellectual development, he states that children and adults use mental patterns (schemes) to guide behaviour or cognition, and they interpret new experiences or material in relation to existing schemes (Cakir, 2008). However, according to O'loughlin (1992), for new material to be assimilated, it must first fit into an existing scheme. When a learner encounters situations in which his/her existing schemes cannot explain new information or experience, existing schemes are changed/transformed through a process Piaget called, accommodation. The condition leading to accommodation is known as disequilibration; that is, the state encountered by a learner in which new information does not fit into an existing scheme (Cakir, 2008).

A flipped classroom approach draws upon Piaget's theory of intellectual development as the focus is on the student's prior understanding and conceptions of pre-class material. In a pre-class material situation, students are given material to read and/or watch in an online video ahead of class to gain a superficial understanding of the content material. According to Jensen, Kummer, and Godoy (2015), a superficial understanding of the content or low-level learning includes definitions and basic content. Student understanding and conceptions of the pre-class material are brought to the surface in the classroom with challenging problems that force students into disequilibration while the instructor is there to guide the students towards accommodation. In the classroom, students are asked to think of an answer to a challenging problem on their own and then discuss solutions with peers. This process is followed by a discussion, led by the instructor (Jensen et al., 2015; Mazur, 2009). In this method, students draw upon their understanding of the pre-class material to identify the correct answer then, hopefully, enhance conceptions through the discussion with peers and the instructor.

The in-class peer-based problem-solving component of a flipped classroom draws upon Vygotsky's learning theories (Jensen et al., 2015). Vygotsky (1978) characterized learning as a social process categorized into two types: (1) everyday learning; and (2) learning that occurs in a formal setting (Cakir, 2008; Karagiorgi & Symeou, 2005). When students learn in a formal setting, they eventually understand how their everyday experiences fit into the system they have been taught and vice versa. Dialogue with the teacher and peers plays a crucial role to bridge the gap between the two categories of learning (Cakir, 2008; Taber, 2011).

An emerging guideline for a flipped classroom suggests that assessment should help students monitor their own learning and hold students accountable for pre-class learning (Persky & McLaughlin, 2017). Assessments for pre-class learning can be done online prior to class or at the start of class. In-class assessments can include questions answered by students using a classroom response system. Post-class assessments provide opportunities for ongoing practice and feedback for students (Persky & McLaughlin, 2017).

2.8.2 Peer Instruction

As in the flipped classroom, Peer Instruction also draws upon a constructivist approach stemming from Vygotsky's (1978) learning theories. Peer Instruction is an in-class interactive pedagogical strategy that promotes classroom interaction to engage students and address difficult aspects of the subject material (Mazur, 2009; Watkins & Mazur, 2013). In peer instruction, the instructor presents a key point followed by a conceptual question and peer discussion (Crouch, Watkins, Fagen, & Mazur, 2007). These questions are targeted to address student difficulties and promote student thinking about challenging concepts. One example of a peer instruction process is for the instructor to pose a multiple-choice question and ask students to think about the question and related concepts. After one to two minutes of thinking, students commit to an individual answer by using a classroom response system such as clickers. If too few students (< 30%) respond with the correct answer, the instructor may revisit the material. If a large majority of students respond correctly (> 70%), the instructor typically gives a brief explanation and moves on. If 30—70% of students answer the question correctly, the instructor asks students to turn to their neighbours and discuss their answers. Students talk in pairs or small groups and are encouraged to find someone with a different answer while the instructor circulates the room to encourage productive discussions and guide student thinking. After several minutes, students answer the same question again and the instructor then explains the correct answer (Watkins & Mazur, 2013).

Peer Instruction is described as "based on a social constructivist approach to learning, in which social interaction plays a crucial role in the construction of knowledge, and where discussion and collaboration between peers have a positive impact on learning." (Michinov, Morice, & Ferrières, 2015, p. 2). Similar to a flipped classroom approach, students are asked to use their prior knowledge to identify the correct answer then enhance their understanding through discussion with peers and the instructor. Research indicates that students are not simply coming up with a correct answer if one of their peers knows the answer but because their discussions are enhancing learning (Smith et al., 2009). Unlike the flipped classroom, Peer

Instruction does not require instruction outside of the classroom which takes place before the topic is discussed (pre-class material) (Crouch et al., 2007).

2.8.3 Guided Inquiry-based Learning in the Laboratory

Inquiry-based pedagogy is heavily based on the work of Lev Vygotsky and his theory of the Zone of Proximal Development (ZPD) (Taber, 2011). Vygotsky's ZPD describes what the learner is not capable of doing unaided but could do with support from a more knowledgeable individual. Learning occurs when individuals are exposed to experiences beyond what they already know but within reach of their current understanding. Thus, scaffolding becomes an important concept emerging from Vygotsky's ideas (Taber, 2011).

The core components of scientific inquiry include: Engaging with scientifically oriented questions; giving priority to evidence and using evidence to develop and evaluate explanations that address scientifically oriented questions; communicating and justifying proposed explanations; and designing and conducting investigations (Minner, Levy, & Century, 2010). The amount of direction and decision-making done by the teacher versus the student's involvement in each component has produced distinctions such as "open-inquiry" and "guided inquiry" (Minner et al., 2010). In guided inquiry-based labs, the instructor poses an initial problem and then guides the students in planning procedures, collecting evidence and developing explanations (Gormally, Brickman, Hallar, & Armstrong, 2009).

Laboratory instructional environments have been criticized as environments where little meaningful learning takes place (Domin, 1999). The instructional activities are often "cookbook" in makeup with emphasis on collecting data using specific, detailed procedures with expected results (Wallace, Tsoi, Calkin, & Darley, 2003). Almost no attention is paid to planning the investigation or analyzing data in order to interpret results. Students spend more time determining if they have obtained the “right” answer rather than actually thinking about the chemistry principles being applied and developing manipulative and observational skills (Johnstone & Al-Shuaili, 2001). Progressing from a more structured, “cookbook” laboratory environment to one of less structure and more inquiry can encourage personal epistemological growth (Mazzarone & Grove, 2013).

2.9 Summary

Personal epistemology is an individual’s beliefs about knowledge and learning, which as discussed above is characterized by three models: (1) Epistemological development models; (2) Multi-dimensional models; and (3) Epistemological resources model. An individual’s epistemology affects how they experience the classroom and the literature suggests that those with naïve epistemologies will have difficulty in university. Research indicates that students entering first-year university tend to have naïve or less informed epistemologies of science as they may view science as a collection of unrelated facts, and as absolute with the source of scientific knowledge being external to them. However, research has also shown that students may develop more sophisticated or informed epistemologies as they progress through university. Pedagogy can promote the development of sophisticated epistemology when teaching methods align with constructivist theories. Specifically, this includes methods where students are discovering the knowledge themselves rather than being told the knowledge, where there is attention to a student’s prior knowledge, and where knowledge is socially constructed. Flipped classroom, peer instruction and inquiry-based learning are pedagogies used in the courses in the context of this study and align with constructivist approach to teaching.

In the next chapter, Chapter 3, I will address the context and purpose of the study, describe the investigative approach as well as outline the methods used to collect and analyze data in order to answer the research questions. This will include a discussion of ethical considerations for the study and a data collection timeline.

Chapter 3: Methodology and Methods

This chapter provides details of the study's context and purpose, and then details the methodology and methods used to answer the research questions. The latter half of the chapter outlines the ethical considerations, timeline for data collection and methods for data analysis.

3.1 Context of Study

The study was carried out with first-year international students enrolled in chemistry courses in the Vantage One Science Program at Vantage College of the University of British Columbia.

3.1.1 University of British Columbia

The University of British Columbia (UBC) is a research-based university with a graduate and undergraduate population consisting of both domestic and international students. In an attempt to increase the international population in undergraduate programs, UBC instituted a separate first-year undergraduate program called Vantage One in September 2014. Prior to the start of Vantage One in 2013, international students made up 16% of the undergraduate population and in 2016, international students made up 23% of the undergraduate program (UBC Enrollment Report, 2018).

3.1.2 Vantage One

Vantage One is a first-year program for international students who do not meet the English language requirements for direct entry admission to UBC but meet all other university requirements (UBC Vantage College, 2017). The 11-month program begins in September and ends in July of the following year. Vantage One combines first-year coursework with academic English courses. Upon successful completion of Vantage One, students progress into the second year of their chosen UBC degree (UBC Vantage College, 2017). The program offers four streams of study labelled Vantage One Arts, Vantage One Engineering, Vantage One Management and Vantage One Science. The program consists of courses with small class sizes and encourages constructivist-based teaching methods including flipped classroom, peer instruction and guided inquiry-based learning.

3.1.2.1 Admissions

Vantage One is only available to international students (no Canadian citizens or permanent residents of Canada) who achieved a minimum International English Language Testing System (IELTS) score of 5.5 but less than 6.5 on the IELTS ("IELTS," 2017). If a student scores 6.5 on IELTS, they are eligible for direct entry to UBC. The academic admission requirements for Vantage One Science Program are the same as UBC admission requirements to Science (UBC Admissions, 2018).

3.1.3 Vantage One Science Program

In 2015/2016, there were two sections of first semester General Chemistry (CHEM 121) for Vantage One Science Program, taught from September-December (Term 1) and two sections of second semester General Chemistry (CHEM 123) in May-July (Term 3). In addition to their chemistry courses, the Vantage One Science students also study Math, Physics and Academic English in Term 1 (Table 3.1). In Term 2, students study Math, Academic English, a science communications course (SCIE 113) and either Earth Sciences or Computer Science. In Term 3, students study Chemistry and Physics plus complete a capstone project for the program. The students take courses as a cohort and class sizes are capped at 75 students, a small population when compared to the first-year science classes for UBC direct entry students.

Vantage One Science Program 2015/2016		
Term 1 (September-December)	**Term 2 (January-April)**	**Term 3 (May-July)**
CHEM 121 Math 100 Physics 117 Academic English Capstone Course	SCIE 113 Math 101 Earth Sciences OR Computer Science Academic English Capstone Course	CHEM 123 Physics 118/119 Capstone project

Table 3-1: Course Schedule in Vantage Science Program 2015/2016

3.1.3.1 Students

In September 2015, at the start of the program, there were 82 Vantage One Science students enrolled in the program and living on campus. Of these 82 students: 69 were from China; 3 students from Ecuador; 1 student from Hong Kong; 1 student from Iran; 1 student from Kazakhstan; 3 students from Korea; 1 student from Russia; 2 students from Saudi Arabia; and 1 student from Singapore. Students came from various high school systems including schools using a Canadian curriculum and international baccalaureate (IB) program. The 82 students were divided into two sections of CHEM 121. By May 2016, the enrollment in the Vantage One Science Program dropped to 72, with 66 students enrolled in CHEM 123.

3.1.4 CHEM 121

The CHEM 121 course consists of a lecture and a laboratory component. These components run separately with different instructors and content of the lab rarely overlaps with the lecture. The following two sections describe the pedagogy used in the lecture and laboratory components of Chemistry 121.

3.1.4.1 Lecture 2015W

UBC enrolls ~2000 students into the first-semester General Chemistry course (CHEM 121). CHEM 121 lecture is team-taught and midterm and final exams are the same among all sections, including the Vantage sections. In addition to common exams, all sections use the same textbook, “Chemistry 121 Integrated Resource Package (ChIRP), and was written by UBC instructors (Gates, Wolf, & Stewart, 2014). There are weekly meetings between all instructors of CHEM 121 to ensure that content and course expectations are consistent among the sections.

In September 2015, the two Vantage lecture sections in this study were taught by this researcher, Anka Lekhi. As described in Chapter 2, a partially flipped classroom approach was used in CHEM 121. Specifically, the pre-class material consisted of readings from ChIRP, as well as videos posted on the online courseware. To hold students accountable for pre-class learning, an online quiz was completed by students before coming to class, which tested for low level content. During class, a ~10 minute summary lecture was delivered before students engaged with peer-based problem-solving. The in-class problems took the form of a worksheet and/or clicker questions and/or questions from the textbook. The instructor was available to answer student questions and check student work. During the last few minutes of class or at the beginning of the following class, the instructor facilitated a discussion of the solutions. Post-class assignments were assigned each week from the textbook. Appendix A (Table A.1) summarizes how marks were assigned in this course.

3.1.4.2 Laboratory 2015W

Recognizing the limitations of a traditional “cookbook” laboratory instruction, the CHEM 121/123 laboratory includes a guided inquiry-based pedagogy (Nussbaum, 2015) outlined in Chapter 2. CHEM 121/123 laboratory applies the principles of guided inquiry-based learning by not giving student answers (such as answers to how the procedure should be written) but instead providing students support in the form of online resources, laboratory manual, access to instructors so the student can find the answer themselves. Student learning is also carefully monitored through formative assessments of student produced work, such as the student written procedure and in-lab observations. In the CHEM 121/123 laboratory, experiments contain scenarios followed by an investigative question for students to answer. For example, in the first experiment, students are given a scenario where a town’s water supply has suspected lead contamination, and the students are asked to determine the amount of lead II ion in a “contaminated sample” using gravimetric analysis. Students are provided with information from their laboratory manual and online resources, including a Virtual Lab Interactive Tutorial, on why lead II ion is measured, what range of concentration can be expected for their sample, as well as a general description of gravimetric analysis (Nussbaum, 2015). Students are expected to come up with the step-by-step procedure on their own before coming to the lab to perform experiment 1. During the lab, the students check their procedure with an instructor and are given guidance to come up with a correct procedure. After the lab, the students write a report.

In 2015W, each experiment in the CHEM 121 lab ran over two weeks. During the first week, called the dry lab, students must complete all the preparation tasks, including writing up the step-by step procedure. In the second week, the students perform the experiment.

3.1.5 CHEM 123

3.1.5.1 Lecture 2016S

UBC enrolls ~1800 students into the second-semester General Chemistry course (CHEM 123). Most of the sections of CHEM 123 are taught in the January-April (Term 2), but the Vantage sections are held in May-July (Term 3). In 2015W/2016S, there was no required textbook for the course, but two optional workbooks, written by UBC instructors, were available.

The Chemistry 123 Vantage lectures were taught by taught by a different instructor than the researcher of this study. As described in Chapter 2, CHEM 123 used Peer Instruction in lectures. Before class, the instructor posted partially completed notes on the course website as well as reading suggestions. Neither the notes or the readings were required to be read by students before class, which is consistent with Peer Instruction teaching (Crouch et al., 2007). During class, the instructor spent some time explaining key points that were followed by conceptual multiple choice questions using electronic response systems (i.e., iclickers) and a peer discussion. Peer Instruction was also delivered using in-class worksheets, or through problem solving at the white board where students were instructed to first think on their own and then discuss in groups. The instructor circulated throughout the room to encourage productive discussions and guide student thinking. The instructor then explained the correct answer to the class. Appendix A (Table A.2) provides a summary of how marks were assigned in this course.

3.1.6 CHEM 123 Laboratory

As in CHEM 121, CHEM 123 Laboratory follows a guided inquiry-based approach (Minner, Levy, and Century, 2010) which involved not giving student answers (such as answers to how the procedure should be written) but instead providing students support in the form of online resources, laboratory manual, and access to instructors so the student can find the answer themselves. Student learning is also carefully monitored through formative assessments of student produced work, such as the student written procedure and in-lab observations. The main difference between CHEM 121 and CHEM 123 laboratories is the written reports in CHEM 123 are more open-ended than CHEM 121 reports. In CHEM 123, students are expected to generate their own lab reports consisting of an Introduction, Data Collection, Discussion, and Conclusion sections.

3.2 The Study

As noted earlier, students entering first-year science courses find university work challenging, probably due to conflicting epistemological positions (Daemplfle, 2004). International students may have difficulties in an active learning environment because of potentially having fewer active learning classroom experiences (Andrade, 2006; Huang, 2012; Pratt et al., 1999a; Yi Zhang, 2016), Despite the large international population in first-year chemistry and the pedagogical innovation in science courses at UBC, there is a lack of literature on understanding of the connections between epistemology, high school and university experiences and pedagogy. To address this problem, this study explored the Vantage One Science student epistemologies with respect to first-year chemistry courses and how these epistemologies evolved over the 11-month program. In addition, the study explored the relationships, if any, between student epistemologies and their experiences in the context of first-year chemistry. To address this problem, the following research questions focused the study design and implementation:

1. What are the personal epistemologies evident among first-year international UBC Vantage College undergraduate students in the Vantage One Science Program at the beginning and the end of Chemistry 121 and Chemistry 123?
2. How are these personal epistemologies affected over the 11 month period in the program?
3. How are these personal epistemologies implicated in student academic performance, study approaches and views of pedagogy used in first-year chemistry?

To answer these questions, an exploratory case study approach with mixed-method methodology that used quantitative and qualitative methods was employed. Quantitative methods were used to assess personal epistemologies over the 11-month Vantage One Science program as well as to determine any correlations between classroom evaluation and epistemology scores. The instrument employed to assess students' epistemology was completed three times by participants during the 11- month first year program, and individual classroom evaluation scores from CHEM 121 and CHEM 123 were collected. Qualitative methods were used to examine epistemology and student views on their experiences. These methods included observations, one-on-one semi-structured reflective and task-based interviews and focus group interviews. The data analysis followed a concurrent triangulation design. The following sections elaborate on the details of the Case Study Approach, Mixed Methods Methodology, Quantitative and Qualitative Data and Data Analysis.

3.3 Investigative Approach: Case Study

I elected to use an exploratory case study to investigate international students' experiences within first year General Chemistry courses in the Vantage One Science Program. A significant portion of this research is an examination of the student experience in context; the two chemistry lectures and laboratory classrooms within the Vantage One Science Program. The individual students serve as cases within a larger case, the context of the two chemistry courses. The exploratory case study aims to explain cause and effect relationships (Tellis, 1997) and thus well suited to this research on how student epistemologies are related to their classroom experiences. An exploratory case study is used in situations where there is no clear single set of outcomes (Yin, 2014). In a case study investigative approach, it is the unit of analysis, not the topic of the research that qualifies the work as a case study (Yin, 2014). Robert Stake's perspective is that "a case study is not a methodological choice but a choice of what is to be studied." (2003, p. 134).

A strength of a case study approach and utilized in this research included multiple data sources and triangulation (Yin, 2012). Merriam argues that while in other kinds of qualitative research only one or two data collection techniques are used, case studies typically involve three techniques including analyzing documents, conducting interviews and making observations. Merriam rationalizes that "the intensive, holistic description and analysis characteristic of a case study, mandates both breadth and depth of data collection." (1998; p. 134). Multiple sources leading to some converging findings is referred to as triangulation (Yin, 2014) and adds to the validity of the findings. For example, many studies use interviews to confirm findings from other data sources or vice versa (Roulston, 2010a). It can also be argued that an interview generates a new data set separate from surveys or observations which adds to the picture being painted. There may be an overlap or convergence between the different sources, but repetition of findings should not be expected. Stake (2003) echoes this view when he states: "Acknowledging that no observation or interpretation are perfectly repeatable, triangulation serves also to clarify meaning by identifying different ways the phenomenon is being seen" (p. 148).

The purpose of case study is not to make generalizations that can be applied to a larger population, but its findings may be "transferrable" to other contexts (Yan Zhang & Wildemuth, 2009). As Yin explains, case study results do not lead to inferences to a population but instead strive for "lessons learned-that is, analytic generalizations-that go beyond the setting for the specific case… that has been studied (Yin, 2014, p. 40). Yin also asserts "…lessons learned from a case study may potentially apply to a variety of situations, far beyond any strict definition of the hypothetical population of like-cases represented by the original case." (p. 41). In reference to case study research, Stake (2003) argues, "… case researchers, like others, pass along to readers some of their personal meanings of events and relationships….[and] the reader, too, will add and subtract, invent and shape-reconstructing the knowledge in ways that leave it differently connected…" (p. 146). This is important because lessons come from the reader of the research so the reader, too, is acknowledged as co-constructing knowledge. Any reader can take the lessons from a case study and freely apply those lessons to their situation. For example, the results of this study can be applied to other contexts such as international first-year programs or first year chemistry courses.

3.4 Research Methodology: Mixed Methods

Research methods are chosen and implemented according to the underlying methodology and the research paradigms in which the study is embedded (Morgan, 2007). For example, research that employs quantitative methods such as surveys and experimentation are typically interpreted to be within the positivist paradigm while qualitative measures such as interviews and observations are typically interpreted to be within the interpretivist paradigm (Guba & Lincoln, 1998). In the positivist paradigm, reality is seen as stable, external to the observer and measurable (Merriam, 1998). Knowledge in this paradigm is gained through scientific methods, and data can be objective and quantifiable. A positivist study aims to minimize bias (and so be objective), for its findings to be generalizable (external validity), accurate within the study (internal validity) and to be able to be replicated by a different researcher (reliable) (Guba & Lincoln, 1998). In contrast, the qualitative paradigm, is based on an interpretive worldview (Guba & Lincoln, 1998). A qualitative study aims to be thorough, comprehensive, coherent, useful and typically involves a small sample size and more contact time between the researcher and the participants (Schwandt, 1998).

Although these associations between the paradigm and the methods are typical, Crotty (1998) argues that "we should accept that, whatever research we engage in, it is possible for either qualitative methods or quantitative methods, or both, to serve our purposes." (p. 15). Studies which include both quantitative and qualitative methods (mixed methods) are controversial because mixing the methods in research implies that mixing the embedded paradigms is possible (Morgan, 2007). Morgan (2007), Johnson and Onwuegbuzie (2004) argue that there is a third paradigm that is linked to mixed methods research as many are embedded within the pragmatic paradigm and system of philosophy. Pragmatism argues that there is no single viewpoint that can ever give the entire picture and that there may be multiple realities. Pragmatism allows a researcher to view the phenomenon from both an interpretive and positivist point of view, for example, and use these to create a practical approach to the problem (Johnson & Onwuegbuzie, 2004). The argument for mixed methods focusses on quantitative research providing a general, wide-angle image of a phenomenon, while qualitative research provides a close-up image that is full of details. Therefore, when used in combination, the results provide a more complete picture than either approach does alone. Proponents of this research paradigm argue that quantitative and qualitative methods are compatible, and both can be used in a single research study. This study employed both quantitative and qualitative methods.

3.5 Methods

I will now discuss the quantitative and qualitative methods used in data collection. Quantitative data were collected using a questionnaire, student academic performance, and study logs, and qualitative data were collected using interviews and classroom observations. While survey data, classroom observations and focus group interviews provided broader social process and generation of meaning in these contexts, the semi-structured interviews, task-based interviews and study logs were all collected from the same 13 students who volunteered.

3.5.1 Quantitative Methods

3.5.1.1 Questionnaire

A survey was administered to measure epistemologies as the instrument provided an efficient method for collecting data on large numbers of students (Hofer & Pintrich, 1997) and also allowed me to study phenomena, that could not be directly observed. In this study, survey methods also provided a means for studying correlations between epistemologies and academic performance (Schommer-Aikins & Easter, 2006). The survey instrument chosen was the Epistemological Beliefs Assessment for Physics Science or EBAPS (White, Elby, Frederiksen, & Schwartz, 1999). The EBAPS survey instrument is embedded within the epistemological resources model. In the epistemological resources model, students' epistemologies are described as “fine-grained cognitive resources whose activation depends on the context” (Hammer & Elby, 2003). Elby (2001) would argue that a learner can hold opposing epistemological views simultaneously and engage one or the other depending on context. For example, students may rely on an authority, such as an instructor to provide strategies for solving a chemistry problem but simultaneously believe that understanding will only come by working through problems independently. The complexity of this kind of student’s epistemological framework cannot be assessed with a generic question regarding the role of authority in transmitting knowledge; context is essential. Thus, the items in the EBAPS survey are heavily contextualized, and many questions ask what students would do rather than what they think (White et al., 1999).

The EBAPS survey consists of 30 items with three different item types: (1) Likert-type ratings of agreement and disagreement items; (2) multiple choice; and (3) debate items. Table 3-2 provides examples for each type of item.

EBAPS Item Type	Item Number	Original Item
Likert-scale (agree/disagree)	2	When it comes to understanding physics or chemistry, remembering facts isn't very important. A: Strongly disagree B: Somewhat disagree C: Neutral D: Somewhat agree E: Strongly agree
Multiple choice	20	In physics and chemistry, how do the most important formulas relate to the most important concepts? Please read all choices before picking one. (a) The major formulas summarize the main concepts; they're not really separate from the concepts. In addition, those formulas are helpful for solving problems. (b) The major formulas are kind of "separate" from the main concepts, since concepts are *ideas*, not equations. Formulas are better characterized as problem-solving tools, without much conceptual meaning. (c) Mostly (a), but a little (b). (d) About half (a) and half (b). (e) Mostly (b), but a little (a).
Debate	26	Justin: When I'm learning science concepts for a test, I like to put things in my own words, so that they make sense to me. Dave: But putting things in your own words doesn't help you learn. The textbook was written by people who know science really well. You should learn things the way the textbook presents them. (a) I agree almost entirely with Justin. (b) Although I agree more with Justin, I think Dave makes some good points. (c) I agree (or disagree) equally with Justin and Dave. (d) Although I agree more with Dave, I think Justin makes some good points. (e) I agree almost entirely with Dave.

Table 3-2: Examples of EBAPS Item Types

Some of the original items in the EBAPS survey contain references to "physics and/or chemistry" (Table 3-2). For these items, "physics and/or" was deleted so the items only referred to chemistry. This wording modification is consistent with the study by Keen-Rocha (2008). All EBAPS items are included in Appendix A (Table A.3).

3.5.1.2 Student Academic Performance

Student academic performance was based on course work in CHEM 121 and CHEM 123. As outlined in Tables A-1 and A-2, students were evaluated through midterm and final exams, weekly quizzes, participation, and laboratory performance. In CHEM 121 and CHEM 123, evaluation of individual student's activities was done either by the instructor team or teaching assistants (TAs). A correlation analysis was done between student individual performance scores with their EBAPS scores to examine any relationships between epistemology and academic performance.

3.5.1.3 Study Logs

The purpose of collecting study log data was to reveal descriptions of study behaviour that could not be directly observed but could be explored during the semi-structured interviews. The choices students made about their study time and activity can provide information about the students' epistemology (Saunders, 1998). For example, students may work with other students frequently outside the classroom or may choose to spend their time reading a textbook. This choice could speak to the students' epistemological view of the source of knowledge (Hofer, 2000). If they are not studying with peers, perhaps they do not view peers or themselves as a source of knowledge. In this study, students were asked to keep a study log during CHEM 123. For efficiency, the study log was essentially a checklist of learning activities outside the classroom (Appendix A). For example, learning activities included, "reading the posted notes" or "re-doing practice problems". Participating students were asked to identify the length of time they spent on each activity and the number of students they worked with during the learning activity. The checklist is provided in Appendix A (Figure A-1). Nonis and Hudson (2006) collected data in a similar way when they asked college students to document how much time they spent on various activities each day of the week for one week; over 25 activities listed. Holschuh (2000) also developed a study strategy checklist for an introductory biology course as a measure of deep and surface strategy use.

3.5.2 Qualitative Methods

Gaining insight into student perspectives can be fruitfully pursued through interviews (Bunce & Cole, 2008). Interviewing is appropriate in studies where the researcher is interested in feelings, thoughts, intentions and previous events since all of these kinds of data cannot be observed (Merriam, 1998). Three types of interviews were conducted and audio-recorded: (1) focus groups; (2) semi-structured one-on-one; and (3) task-based interviews. In the following sections, I will provide the details of the approach and methods used to conduct these interviews. In addition, classroom observations were also collected in an effort to aid in understanding student epistemologies and experiences.

3.5.2.1 Focus Group Interviews

The purpose of the focus group interviews was to collect interview material efficiently and to provide an opportunity to observe the process of meaning generation and social interaction (Pratt, 2002). The unique quality of a focus group interview is the social interaction between and among group members; participants are influencing and are being influenced by others, which is representative of real life (Dilshad & Latif, 2013). Participants are encouraged to interact with each other and do not merely respond to the interviewer, allowing for a range and complexity of attitudes and beliefs to emerge (Krueger & Casey, 2010).

Two sets of 60-minute focus group interviews were conducted to coincide with the students' chemistry course schedule allowing the researcher to ask students probing questions about experiences in their chemistry courses while the course was fresh in their minds. The first set occurred in January 2016 (end of CHEM 121) and the second set occurred in May 2016 (start of CHEM 123). The total number of participants in the January and May focus group sessions was 32 and 11 students, respectively. The size of each focus group ranged from four to twelve participants. Many authors suggest that the size of the focus group should range from six to twelve participants (Dilshad & Latif, 2013). However, focus groups can number as small as four when participants know each other (as they did in this study) and when participants are reporting on their own in-depth experiences (Dilshad & Latif, 2013; Krueger & Casey, 2010). The first set of focus group interviews consisted of questions designed to elucidate participants' reflections on their experiences of CHEM 121 (Appendix A; Table A-5), and the second set of focus group interviews consisted of questions designed to probe participants' views of knowledge and their reflections on the start of CHEM 123 (Appendix A; Table A-6). The focus group interview questions were informed by my classroom observations, the students' study logs, the questionnaire responses, as well as the literature review.

3.5.2.2 Semi-structured One-on-One Interviews

The semi-structured interviews served as a way to understand the quantitative data and to gain insights into the students' thoughts, experiences, beliefs, and feelings (Ornek, 2008; Roulston, 2010b). The interviews focused on understanding student views of knowledge using questions which probed students' beliefs about the nature of chemistry knowledge, the process of acquiring chemistry knowledge, how chemistry knowledge is created, the source of chemistry knowledge, students' views on preferences of learning environments, and self-reflection about their own competencies and abilities in chemistry (Appendix A). The questions were inspired by classroom observations, study logs, questionnaire responses, as well as a literature review.

In the interviews, an open-ended, exploratory approach was used as open-ended interview questions do not bound the interviewee to alternatives provided by the interviewer or force any time contraints on responses (Schensul & LeCompte, 2013). I chose an exploratory approach because I wanted to understand students' experiences, and have the flexibility to follow-up on any unanticipated topics arising from the interview. Asking exploratory and open-ended questions assumes that individual participants define the world in unique ways and allows the researcher to respond to the situation at hand (Merriam, 1998).

Two sets of 40-minute one-on-one interviews were conducted. The first set occurred in May 2016 (at the start of CHEM 123) and the second set occurred in July 2016 (at the end of CHEM 123). The timings coinciding with when the EBAPS questionnaire was administered which allowed for the opportunity for follow-up questions to deepen understanding of survey responses (although the EBAPS survey are also administered in September 2015, interviews were not conducted in September because the researcher was also teaching the participants at that time). As advised by Kvale (2007), I prepared an interview guide for the each interview which is summarized in Appendix A; Tables A-7 and A-8 to remind me of some of the main points I wanted to address during the interview.

3.5.2.3 Task-based Interviews

Two task-based interviews lasting approximately 20 minutes were conducted following the semi-structured interview. Each student was given chemistry problems (Appendix A; Tables A-7 and A-8) and asked to verbalize their strategy in solving the problem (Lising & Elby, 2005), following Think Aloud protocol (Ericsson and Simon, 1993). Think-aloud protocol interviewing reveals a person's thought process when solving problems (Ornek, 2008). For the students to feel comfortable explaining or re-explaining, it was important to minimize the power-distance between the participants and me. To accomplish this, I used verbal and non-verbal cues to express a caring and casual demeanor (Finlay, 2012). The intent of the task-based interview was to provide an opportunity to understand deeper the meanings behind epistemology and to generate data connected to the survey data, rather than a verification of the survey data (Roulston, 2010a, p. 86). For example, when faced with a problem, will the students first try to relate their own personal experiences to answer the question or try to recall something that they have read or heard from an instructor? These two strategies indicate different epistemology (Hofer & Pintrich, 1997; Liu & Tsai, 2008).

3.5.2.4 Observations and Reflections

The majority of the qualitative data collection in Term 1 occurred through classroom observations and my own reflections as the instructor of CHEM 121. In Term 2, I attended the CHEM 123 lecture and laboratory classes acting as an observer. As suggested by Merriam (1998) and Hatch (2002), I kept written field notes of my observations and reflections in a research journal to maintain an "on the spot record" (2002, p. 88). I documented the students' actions and behaviours, and engagement in activities by detailing their interactions. During both CHEM 121 and CHEM 123, most of my focus was the class as a whole, and not any individual students. According to Merriam (1998), such observations and reflections can provide specific incidents that serve as reference points for the one-on-one interviews. I took a semi-structured approach to the reflections and observations (Merriam, 1998) as I had some points in mind to focus on including student engagement in response to different pedagogies, such as peer-learning activities. In addition, I also focused on how students related to, and interacted with, the instructors. However, I also allowed the focus points for the classroom observations to change over the course of the study depending on the one-on-one interviews and the events in class.

In preparation for the interviews, I drew upon my classroom observations of appropriate incidents and instructor quotes as topics for questioning. For example, students were reminded of statements made by the CHEM 123 instructor and were asked what they thought the statement meant to them.

3.6 Ethical Considerations in Research Design

In this section, I will outline how I recruited students and my researcher role. I will include a description of research bias and what was done to minimize research bias. I also include a description of the study's Ethics Approval process.

3.6.1 Recruitment

All 82 Vantage One Science students were invited to participate in the EBAPS survey on September 18-24 2015 via a classroom announcement by the researcher's colleague. Paper copies of the survey were provided with a consent to participate form attached (Appendix A). The consent form outlined that the researcher may also view individual "…Chemistry 121 and 123 grades and any formal assessments, including exams, quizzes and reports." (Appendix A). In addition to the EBAPS questions, students were also asked to submit their UBC student number for tracking purposes. The surveys were kept secure by a colleague until CHEM 121 was completed to ensure that I did not know who completed the surveys while I was their instructor. A total of 75 (N = 75) out of a potential 82 students completed the survey in September. The

Vantage One Science students were again invited via a classroom announcement to respond to the same questionnaire on two more occasions: May 2016 and July 2016. In May 2016, 66 students (N = 66) participated and in July, 53 (N=53) participated. Paper copies of the survey were provided with a consent to participate form attached (Appendix A).

All of the Vantage One Science students were invited to participate in a focus group interview via a classroom announcement on January 8 2016. Thirty-two students volunteered and selected one of four possible times to attend the focus group interview on January 14 and 15th, 2016. Each of the focus groups consisted of four to twelve participants. All of the Vantage Science students were invited to participate in a focus group interview via a classroom announcement on May 12th, 2016. Eleven students volunteered to participate in a focus group interview and signed up for one of two possible times to attend the interview.

All of Vantage One Science students were invited to participate in a set of two one-on-one interviews, two task-based interviews and to complete a study log via a classroom announcement in May 12th, 2016. Thirteen students volunteered to participate.

The recruitment approach may have introduced a selection bias due to the possibility that students who volunteered may have been interested in the topic of the study, and thus may have different characteristics than the overall study sample.

All interviews were audio recorded and transcribed for future analysis.

3.6.2 Ethics Approval

I successfully applied to the Behavioral Research Ethics Board (BREB) for approval (H14-02058). In accordance with BREB procedures, all participants received a "Consent to Participate" letter outlining the principal investigator(s) and the conditions for participating in and withdrawing from the study (see Appendix A; Tables A-4, A-11, and A-12). Students were tracked using their UBC student numbers. To maintain privacy and confidentiality, pseudonyms were used for all participants in all reports related to the research. All data were stored on an encry pted password-protected computer and physical documents were stored in a locked file cabinet at UBC.

3.6.3 Researcher Bias

There is a certain element of bias that this researcher brings to the study as the instructor of CHEM 121. However, threats to the validity and integrity of the data were minimized. First, recruitment was done by the researcher's colleague to minimize the power dynamic. Since I was an instructor in the program, it was important to ensure that students knew they would not be compromised, in any way, for not participating in the research. Second, the completed surveys were kept by my colleague in a locked cabinet until after the completion of CHEM 121 when grades had been assigned and entered. Third, most of the data collection occurred after the completion of CHEM 121, when I was their instructor. Bias may have occurred if students answered the interview questions the way they believe they should in their role as study participants. In particular, students may have been tempted to provide desirable answers since they knew me as an instructor. This is also known as the Hawthorne Effect which is defined as how participants' behaviours might change when they become engaged in a research study (Gay, Mills, & Airasian, 2006). In particular, students may have been tempted to provide desirable answers since they knew me as an instructor. I attempted to minimize the Hawthorne Effect by giving a small amount of feedback and not responding to their responses as being right or wrong (Adair, 1984). I further discuss reliability and validity issues at the end of this chapter.

3.6.3.1 Reflexivity

Reflexivity is a tool to improve the quality, rigor, and validity of the research findings and involves researchers critically analyzing their own role in the research process (Finlay, 2003). For example, when conducting interviews, I acknowledge that the findings are the result of the dialogue between myself and the interviewee so any meaning-making is co-constructed (Finlay, 2012). The interpretations presented in this thesis are shaped by my own perspective (Creswell & Miller, 2000), but I attempted to be transparent about my rationales for methodological choices and data interpretation to enable my committee, serving as an external audit, to verify my results. During the interviews, I tried not to assume meanings when the interviewees spoke of their experiences and frequently checked with the interviewees to clarify my own understanding. For example, some of the differences the interviewees' spoke of between their previous schools and university were similar to experiences my parents (who are immigrants) have communicated to me. However, I tried not to let my prior personal views influence my understandings of the interviewees' experiences.

3.7 Data Collection Timeline

In Terms 1 (September-December 2015), 2 (January-April 2016) and 3 (May-July 2016), the EBAPS survey was administered, see Appendix A. In Term 2, focus group interviews were held regarding experiences in CHEM 121. In Term 3, a second set of focus group interviews were conducted, along with two sets of one-on-one semi-structured and task-based interviews. In Terms 1 and 3, scores for exams, quizzes and assignments were collected for analysis. I maintained a journal that includes my observations and insights from teaching in Term 1 and from the perspective of an observer in Term 3. A summary of the data collection timeline is shown in Table 3.3.

Sep 2015 START OF TERM 1	Sep-Dec 2015	Dec 2015	Jan. 2016 START OF TERM 2	Feb-Apr 2016	May 2016 START OF TERM 3	May-Jul 2016	Jul. 2016 END OF YEAR 1
EBAPS Sept 18 2015	Instructor Reflection Journal	Collection of Student Exams, quizzes and assignments.	Recruitment of Participants for focus groups	Focus group interviews.	EBAPS and Recruitment of Participants for one-on-one interviews and focus groups	Classroom Observations Focus Group Interviews and one-on-one interviews	EBAPS and Collection of Student Exams & Quizzes & Assignments. One-on-one interviews
CHEM 121			NO CHEM COURSE		CHEM 123		

Table 3-3: Data Collection Timeline

3.8 Data Analysis

Concurrent triangulation applies to study designs when the data is triangulated at the data analysis and interpretation phase (Cresswell, Plano-Clark, Gutmann, & Hanson, 2003). The following three steps during data analysis in this study are consistent with Concurrent Triangulation design: (1) Qualifying quantitative data: Using factor analysis to examine the survey data. These factors then become themes; (2) Use thematic analysis to analyze qualitative data; and (3) The results from the quantitative and qualitative data were compared by looking for collaborations to form new variables (Cresswell et al., 2003). In the following sections, I provide details on the data analysis procedures used for the quantitative and qualitative data sets, as well as the combination of both. I will begin with quantitative data analysis.

3.8.1 Quantitative Data Analysis

As described in section 3.6.1, the questionnaire data were collected at three points during the Vantage program. These points or "Rounds" have been defined as:

- $Round_{SEPT}$: questionnaire gathered at the start of the Vantage program and CHEM 121 in September 2015;
- $Round_{MAY}$ - questionnaire and related interview data gathered at the end of 8 months of the program and at the start of CHEM 123 in May 2016;
- $Round_{JULY}$ - questionnaire and related interview data gathered at the end of CHEM 123 and the Vantage program in July 2016.

The statistical software IBM SPSS version 24 and AMOS 24 was used to perform the analysis of the questionnaire data. A list of statistical tests is provided in Table 3-4 and full descriptions are provided in the subsequent sections. Unless otherwise indicated, the significance level for a hypothesis test is a *p*-value less than or equal to 0.05.

Software	Statistical Test	Description of Test
SPSS 24	Descriptive Analysis of Survey Scores	Mean score, standard deviation and standard error of $Round_{SEPT}$, $Round_{MAY}$, $Round_{JULY}$
	One-way Repeated Measures ANOVA	Examines whether the students, who completed the survey all three times (N = 48), changed over time as a single unit.
	Correlation Analysis	Identifies any correlations between survey responses and student grades.
SPSS 24 and	Exploratory and Confirmatory Factor Analysis	Evaluate the emergent factors of epistemology among participating students and how dominant factors changed over time.

AMOS 24		
SPSS 24	Cronbach Alpha	Evaluates the internal consistency of the emergent factors resulting from Exploratory Factor Analysis. It determines how much the items in a factor are measuring the same underlying dimension by considering the mean inter-item covariance

Table 3-4: List of Statistical Analysis

3.8.1.1 Questionnaire Scoring

The EBAPS scoring ranged from 0 (least sophisticated) to 4.0 (most sophisticated) (Elby, 2001; Ornek, 2015). The original study used a non linear scoring so different questions were scored differently. For example, in some items, strongly agree was given a score of 4.0 because "strongly agree" represented the most sophisticated answer choice but in a different question, strongly agree was given a score of zero because it represented the least sophisticated answer choice. The neutral option (option "C") was sometimes given a score of "2.0" but other items scored as "1.5" or "2.5" (White et al., 1999). The rationale was that sometimes choosing "neutral" was a more or less sophisticated answer for certain questions.

I transformed the scoring from what was used by White et al., (1999) prior to data analysis as shown in Table 3.5. The items were scored from 1 (least sophisticated) to 5 (most sophisticated) with 1-point intervals. Since zero does not mean zero level of epistemological view, zero was avoided during statistical analysis. With ordinal data, it is inherent that the difference between the values of 1 and 2 may not be the same as the difference between 4 and 5 which is why I chose not to use 0.5 increments in my scoring, as modelled by White et al., 1999. Table 3.5 summarizes the difference in scoring between White et al., 1999 and the current study.

Rating of response choices	Scoring	
	White et al., (1999)	This Study

Least sophisticated	0.0	1
Somewhat un- sophisticated	1.0	2
Neutral	1.5, 2.0 OR 2.5	3
Somewhat sophisticated	3.0	4
Most sophisticated	4.0	5

Table 3-5: Questionnaire Scoring

3.8.1.2 Descriptive Analysis and One-way Repeated Measures ANOVA

Descriptive analysis included mean overall and factor scores of $Round_{SEPT}$, $Round_{MAY}$, and $Round_{JULY}$ in addition to standard deviation and standard error scores. A one-way repeated measures ANOVA was used to examine whether there were any significant differences in the mean scores on the EBAPS questionnaire across time for students who completed the questionnaire for all three rounds (48 students). In order to run the one-way repeated ANOVA test, we make the following assumptions:

(a) The overall EBAPS scores from each round are a continuous variable

(b) The overall EBAPS scores from each round are approximately normally distributed

(c) Known as sphericity, the variances of the differences between all combinations of rounds must be equal

3.8.1.3 Correlation Analysis

To examine whether there is a relationship between the epistemologies of students entering first-year university and their experiences of pedagogy in CHEM 121 and CHEM 123, SPSS version 24 was used to calculate a Pearson coefficient between various CHEM 121 and CHEM 123 classroom scores (such as final exam scores, homework scores, laboratory scores, etc) with questionnaire scores. Since they are the same students in two different courses, any other external forces are cancelled out and, as these are quasi studies and not experimental, it involves studying the student epistemologies in situ. Student performance is only one aspect of the student experience in first year. Other aspects are discussed throughout the thesis, including in the qualitative analysis. Schrommer (1993) ran a similar analysis when she looked at the relationship between epistemology scores and high school GPA using correlation coefficient.

The Pearson coefficient measures the strength and direction of a linear relationship between two continuous variables. Here are the assumptions:

a) Both variables are continuous
b) The scores from survey items is ordinal data but aggregated scores that are obtained from multi-item surveys can be considered "reasonably continuous or interval" (Furr and Bacharach, 2013). The scores used for correlations are aggregated from all items (Overall) or from items in each factor from $\text{Model}_{\text{SEPT}}$. There is controversy over whether aggregated scores can be treated as continuous (Furr & Bacharach, 2013)
c) There is a linear relationship between the two variables
d) There are no significant outliers
e) Bivariate normality (large sample size, >50, Pearson coefficient is not sensitive to non- normality).

3.8.1.4 Analysis: Emergent Components of Epistemology among Vantage One Science Students

Psychometric analysis of EBAPS included a combination of exploratory and confirmatory factor analyses using SPSS and AMOS versions 24 to assess the emergent components of epistemology followed by reliability analysis (Henson & Roberts, 2006). This process involved identifying the dominant factor structure at entry into the program and studying the effect of the program on these factors (Anderson & Nashon, 2007). The dominant factors underlying the students' responses to the items on the EBAPS were interpreted as a description of the key student epistemologies (Furr & Bacharach, 2013). Exploratory factor analysis (EFA) can be used to see what factors emerge from actual data (Johnson & Stevens, 2001). The analysis is based on the correlations between variables (in this case, questionnaire items) (Furr & Bacharach, 2013). The factors that explain the highest proportion of variance that the items share are expected to represent the underlying constructs. In this study, EFA led to three models, consisting of different dimensions ($Model_{SEPT}$, $Model_{MAY}$ and $Model_{JULY}$). For each factor, a Cronbach's alpha (α) was determined to measure the reliability of the factors within each model. In order to see how the models held up over time, confirmatory factor analysis (CFA) was performed for each model on subsequent rounds. CFA can readily be used to test rival models and to quantify the fit of each rival model (Thompson & Daniel, 1996). I also performed CFA of the model put forth by the authors of EBAPS ($Model_{EBAPS}$) on each round ($Round_{SEPT}$, $Round_{MAY}$, $Round_{JULY}$) using AMOS version 24. Confirmatory factor analysis can be used to determine if the dimensions or factors of an established theory hold up to a dataset (Henson & Roberts, 2006; Justicia, Pichardo, Cano, Berben, & De la Fuente, 2008).

The suitability of exploratory factor analysis on the data collected was assessed prior to analysis (Furr & Bacharach, 2013). This assessment included Bartlett's test of sphericity and the Kaiser-Meyer-Olkin (KMO) test of sampling adequacy. The Kaiser-Meyer-Olkin test of sampling adequacy is a ratio of shared inter-item variance to total variance. A general rule of thumb is that KMO should be at least .60 to consider factor analysis appropriate for the data. Bartlett's test of spherictiy is a statistical test of the null hypothesis that the correlation matrix is an identity matrix (an identity matrix is a correlation matrix where the correlations between variables other than themselves is zero). A significant value ($p < 0.05$) indicates that the correlation matrix differs significantly from identity (Furr & Bacharach, 2013). These diagnostic procedures were followed by exploratory factor analysis. The following criteria were used to determine principle factors:

1. Only factors with an eigenvalue higher than 1 were accepted as common factors.
2. A factor was only retained if it explained at least 5% of the total variance
3. The components to be retained are those before the inflection point of the scree plot
4. Each factor had at least three items with most item loadings greater than 0.30 (some exceptions with loadings > 0.2) and these items assessed the same construct.

In this study, the sample size ranged from 53 to 75 which is acceptable as confirmatory factor analysis requires a minimum sample size of 50, for simple models, like the factor structures used in this study (Furr & Bacharach, 2013). The factor structure model for EBAPS ($Model_{EBAPS}$) consists of items that relate to one of five factors. The statistical software, (AMOS) calculates the degree of variance for each item and the degree of covariance between the items in a factor. The software also calculates implied variances and covariances. For example, if two items load strongly onto one factor, this implies that the items will have a significant covariance. In a complex model, one could end up with a large number of covariances and variances. This is analogous to having multiple unknowns with multiple equations. The degree of match between the implied (or calculated) covariances and variances with the actual variance and covariance of the data describes how well the model fits (Furr & Bacharach, 2013).

Model goodness of fit can be evaluated using several indices, including, Chi-square (CMIN), Chi-square/*df* ratio (CMIN/df), Goodness-of-Fit Index (GFI), Adjusted Goodness-of-Fit Index (AGFI), Comparative Fit Index (CFI), Root-Mean-Square Error of Approximation (RMSEA), and the Tucker-Lewis index (TLI). GFI, AGFI, TLI, CFI values usually range from 0 to 1.0, with higher values considered to be evidence of good model fit (Johnson & Stevens, 2001). RMSEA values of less than 0.06 indicate good model fit (Hu & Bentler, 1999). A small chi-squared (CMIN) value indicates a good fit. One difficulty with the chi-squared test of model fit, however, is that researchers may fail to reject an inappropriate model in small sample sizes and reject an appropriate model in large sample sizes (Gatignon, 2010). Taking CMIN and dividing by the degrees of freedom (df) is often reported. A CMIN/df less than 5 with a $P > 0.5$ indicates a permissible fit (Hu & Bentler, 1999). In the current study, I used CMIN/df and CFI. CFI ranges from 0 to 1.0, with values greater than 0.7 indicating a good fit (Furr & Bacharach, 2013). The models were also tested using one-way repeated measuring ANOVA for triangulation.

3.8.2 Qualitative Data Analysis

3.8.2.1 Classroom Observations, Reflections and Study Log

Reflections from teaching CHEM 121, classroom observations of CHEM 123 lecture and laboratory, and the study logs completed by participating students provided the context that informed follow-up interview questions and discussions. In preparation for the interviews, I drew upon my reflections and classroom observations of appropriate incidents and instructor quotes as topics for questioning. For example, students were reminded of their responses to different pedagogies, such as, group work in CHEM 121 and asked to explain their behaviour.

3.8.2.2 Interviews

The interviews were audio recorded and transcribed for the purpose of analysis. I used an iterative approach for the data analysis (Grbich, 2007). The initial step of analysis involved preliminary data analysis where every time data were collected (every interview), I reflected and documented all relevant data in reference to the research questions, emerging themes, and areas that required follow-up (Grbich, 2007). My analysis was guided by broader descriptions of epistemology informed by the literature (Baxter Magolda, 1992; Hofer & Pintrich, 1997; Louca et al., 2004; Schommer, 1990). I compared participants' responses across one another and within each participant, identifying not only similarities but also differences between them (Ornek, 2008). During the preliminary process, I identified emergent patterns.

Thick description in the form of a transcript (Grbich, 2007) for each interview data set was generated. After the interviews were completed and transcribed, I categorized the data using thematic analysis (Merriam, 1998; Miles & Huberman, 1994) to address the study objectives

(Miles & Huberman, 1994; Yin, 2014). Thematic analysis is a search for themes that are identified through careful reading and re-reading of data important to the description of the phenomenon being studied (Fereday & Muir-Cochrane, 2006). I referred to my preliminary notes as I generated themes. At this stage, I also focused on each student as a “case”, and I viewed all the data from one student as a whole (Yin, 2014). I followed Aronson’s (1995) approach to thematic analysis: First, the researcher looks for patterns of experiences and then identifies all relevant data to each pattern. The next step is to combine and catalogue related patterns into themes. Themes consist of components and ideas that fit together in a meaningful way. Finally, the last step is to incorporate literature to support arguments for the themes (Aronson, 1995). I sifted through transcripts of each interview data set to identify, describe, and interpret themes related to student epistemologies as well as to document any changes in their epistemologies.

3.8.3 Validity and Reliability in Quantitative and Qualitative Data Analysis

Quantitative Data Analysis

The use of reliability and validity are common in quantitative research and are rooted in a positivist perspective (Golafshani, 2003). Reliability of data refers to whether a result is replicable, and validity refers to the accuracy of the data and whether an instrument is measuring what is intended to be measured (Gay et al., 2006). In this study, the quantitative data included a questionnaire. The internal reliability or consistency of a questionnaire refers to items in the same domain or factor having corresponding responses because they probe the same attribute. Cronbach alpha was used to measure internal consistency. It is used to determine how much the items in a factor are measuring the same underlying dimension by considering the mean inter-item covariance (Cortina, 1993). Keen-rocha, (2008) reported a Cronbach alpha of 0.7 in a study where EBAPS was administered to 56 Chemistry students. A Cronbach alpha, (α) of .70 or higher is considered acceptable (Anderson & Nashon, 2007; Peterson, 1994). However, Cronbach alpha depends on the number of items in each factor. A low Cronbach alpha may just reflect lower items in the dimension (Cortina, 1993). Cortina (1993) concluded that if a scale has enough items (i.e., more than 20), then it can have an alpha of greater than .70 even when the correlation among items is very small. Nunnally (1978) has been cited in many current studies in support of using reliability coefficient (α) of .70 (Peterson, 1994). However, Nunnally changed his reliability recommendations from his 1967 edition of Psychometric Theory in his 1978 edition. In 1967, he recommended that the minimally acceptable reliability for preliminary research should be in the range of 0.5 to 0.6, whereas in 1978 he increased the recommended level to 0.7 (without an explanation) (Peterson, 1994). White et al., 1999 propose a subscale structure to their instrument and the reliability of the subscale, or factor structure posed by White et al., 1999 ($Model_{EBAPS}$) was tested in this study for these student responses using confirmatory factor analysis (Justicia et al., 2008).

The external reliability or stability of an instrument refers to how repeatable the results are. If the questionnaire was to be re-tested by the same individual, the results should be the same. A high degree of stability indicates a high degree of reliability, which means the results are repeatable (Golafshani, 2003). However, it must be acknowledged that measuring the stability of an instrument is problematic using test/re-test method because test-retest method may sensitize the respondent to the subject matter, and influence the responses given or the respondent may have a change in attitude (Golafshani, 2003).

The EBAPS instrument is a peer-reviewed instrument and has been used extensively (Elby, 2001; Keen-Rocha, 2008; Muis & Gierus, 2014; Ornek, 2015; Pulmones, 2010; Yildiran, Demirci, Tüysüz, Bektas, & Geban, 2011), which speaks to the instrument's validity. The validity of an instrument can also be measured by comparing the results against another established instrument or by interviewing respondents (Golafshani, 2003). During the interviews respondents are asked to explain their answers which is then checked against the intention of the item (alternatively, participants can be asked to explain their answer choices) (Krosnick, 1999). It is important to have a large and representative sample so that the findings can be generalized to a larger population. This process ensures items on the survey are clear and measure what is intended (Krosnick, 1999). The EBAPS instrument was validated through revision based on pilot participants. White et al., (1999) administered the EBAPS survey to 100 ethnically and socioeconomically diverse students drawn from six separate community colleges in northern California. These students were asked to write down their reasons for their responses to each item.

Qualitative Data Analysis

Reliability and validity are viewed differently by qualitative researchers. Reliability and validity are conceptualized as trustworthiness, rigor and quality in qualitative paradigms (Golafshani, 2003). Denzin and Lincoln (1994) suggest that four factors should be considered in establishing the trustworthiness of findings from qualitative research: (1) transferability; (2) dependability; (3) confirmability; and (4) credibility. Transferability means that researchers can apply the findings of the study to their own context. This can be accomplished through detailed descriptions of the participants, the data collection procedures, the analytic procedures, and the emergent patterns. Lincoln and Guba (1985, p. 300) use “dependability”, in qualitative research, which closely corresponds to the notion of “reliability” in quantitative research. According to Denzin and Lincoln (1994), dependability refers to the stability of the findings over time and coherence of the data in relation to the findings, interpretations, and recommendations. This is accomplished by presenting the rationale for selecting participants and events to observe. A technique for assessing dependability is the dependability audit where an independent auditor reviews the activities of the investigator. Confirmability refers to the quality of the results, the degree to which qualitative data and their interpretations can be authenticated. Credibility refers to confidence in the truth of the findings (Denzin & Lincoln, 1994).

This study provides rich descriptions of the participants, context, data collection and analysis procedures to ensure the findings can be transferable to another context. To ensure dependability, this study incorporated rationales for experimental design into the methodology and methods section of this thesis. Also, an independent audit, in the form of peer review by my thesis committee members was used to accomplish dependability and confirmability simultaneously (Guba & Lincoln, 1998). This study aims to establish credibility through triangulation, which is described in the next section.

3.8.4 Relating Results from Quantitative and Qualitative Data Analyses: Triangulation

Triangulation is defined to be “a validity procedure where researchers search for convergence among multiple and different sources of information to form themes or categories in a study” (Creswell & Miller, 2000), p. 126). A strength of a mixed methods study is that data collected from multiple sources through multiple methods has the potential to offset the weaknesses inherent within one method due to the strengths of the other method. Where quantitative data provides the breadth, the depth is provided by qualitative data (Gay et al., 2006) Triangulation is a way of corroboration that allows the researcher to be more confident in the study's conclusions since the conclusion is based on multiple forms of evidence rather than one data point. However, triangulation does not always lead to convergence of data; it may lead to inconsistencies or contradictions (Mathison, 1988). The value of triangulation is the richness of data and evidence from which the researcher can construct meaningful explanations (Mathison, 1988).

This mixed-method study was designed for concurrent triangulation (Cresswell et al., 2003). Concurrent triangulation applies to study designs for which the qualitative data and quantitative data were collected concurrently and triangulated at the data interpretation phase. First, I analyzed the quantitative data. The analysis led to themes. I then analyzed the qualitative data using thematic analysis. Finally, I compared the results and looked for collaborations to form new key themes. My focus was to look for ways in which the interview data supported and differed from the quantitative data findings (Cresswell et al., 2003).

3.9 Summary

This study employed a case study approach that used mixed methods to investigate the research questions. The EBAPS instrument used to assess student epistemology was completed three times by each participant during the 11-month first year program and was analyzed for emergent epistemological factors using exploratory and confirmatory factor analysis. Individual classroom activity grades from CHEM 121 and CHEM 123 were collected and correlated with scores from EBAPS questionnaire. Student study logs were also collected.

Qualitative methods were used to examine epistemology and students' views on their experiences. These methods included observations, one-on-one semi-structured and task-based interviews, and focus group interviews. Table 3-6 provides a summary of the methods used to address each research question.

Research Question	Quantitative Method	Qualitative Method
What are the personal epistemologies evident among first-year international UBC Vantage undergraduate students at the start of their first-year and their first Chemistry course, (September 2015), after 8 months of the Vantage program but before they begin their second Chemistry course (May 2016), at the end of their second Chemistry class and the Vantage program (July 2016)?	Statistical Analysis of EBAPS Questionnaire: • Descriptive Statistics • Exploratory and confirmatory factor analysis	Focus Group interviews One-on-one semi-structured interviews Classroom Observations Study logs
How do these personal epistemologies evolve over the 11 month program?	Statistical Analysis of EBAPS Questionnaire: • Comparing Descriptive Statistics over time • One-way Repeated Measures ANOVA • Comparing Models that emerged from Exploratory factor analysis over time	Focus Group interviews One-on-one semi-structured interviews Classroom Observations
How do these personal epistemologies relate to the student experience, including academic performance, study approaches and student views of pedagogy used in first-year chemistry?	Pearson Correlation Coefficient between EPAPS scores and CHEM 121 and CHEM 123 grades	Task-based interview Focus Group interviews One-on-one semi-structured interviews Classroom Observations

Table 3-6: Summary of Methods Used to Address Research Questions

I will present the quantitative data, analysis and indicate the results in the next chapter.

Chapter 4: Quantitative Data Analysis

This chapter reports on the analyses of the questionnaire data from which dominant aspects (factors) of student epistemologies were analyzed and interpreted. The chapter begins with a discussion of the EBAPS questionnaire, followed by the results from descriptive statistics and one-way repeated measures ANOVA. A significant portion of the chapter discusses the emergent aspects of student epistemologies and how they were affected over time which, were determined by exploratory and confirmatory factor analysis methods. Lastly, the chapter presents results from correlation analysis between EBAPS scores and student grades in CHEM 121 and CHEM 123.

4.1 The Questionnaire

Student epistemologies were investigated by administering the Epistemological Beliefs Assessment for Physical Sciences (EBAPS), developed by White, Elby, Frederiksen, and Schwartz (1999). The questionnaire was administered at three points during the 11-month Vantage One Science program. These points or “Rounds” have been defined as:

- $Round_{SEPT}$: questionnaire gathered at the start of the Vantage program and CHEM 121 in September 2015;
- $Round_{MAY}$ - questionnaire and related interview data gathered at the end of 8 months of the program and at the start of CHEM 123 in May 2016;
- $Round_{JULY}$ - questionnaire and related interview data gathered at the end of CHEM 123 and the Vantage program in July 2016.

The EBAPS contains 17 agree-disagree items on a five-point scale, six multiple-choice items, and seven conversation items for a total of 30. Many EBAPS items attempt to provide context-based questions that ask students what they would do rather than what they think (White et al., 1999). Table 4.1 contains all the items in the survey. For the full survey, see Appendix A.

1. Tamara just read something in her science textbook that seems to disagree with her own experiences. But to learn science well, Tamara shouldn't think about her own experiences; she should just focus on what the book says.
2. When it comes to understanding physics or chemistry, remembering facts isn't very important.
3.Obviously, computer simulations can predict the behavior of physical objects like comets. But simulations can also help scientists estimate things involving the behavior of *people*, such as how many people will buy new television sets next year.
4. When it comes to science, most students either learn things quickly, or not at all.
5. If someone is having trouble in physics or chemistry class, studying in a better way can make a big difference.
6. When it comes to controversial topics such as which foods cause cancer, there's no way for scientists to evaluate which scientific studies are the best. Everything's up in the air!
7. A teacher once said, "I don't *really* understand something until I teach it." But actually, teaching doesn't help a teacher understand the material better; it just reminds her of how much he or she already knows.
8. Scientists should spend almost all their time gathering information. Worrying about theories can't really help us understand anything.
9. Someone who doesn't have high natural ability can still learn the material well even in a hard chemistry or physics class.
10. Often, a scientific principle or theory just doesn't make sense. In those cases, you have to accept it and move on, because not everything in science is supposed to make sense.
11. When handing in a physics or chemistry test, you can generally have a sense of well you did even before talking about it with other students.
12. When learning science, people can understand the material better if they relate it to their own ideas.
13. If physics and chemistry teachers gave *really clear* lectures, with plenty of real-life examples and sample problems, then most good students could learn those subjects without doing lots of sample questions and practice problems on their own.
14. Understanding science is really important for people who design rockets, but not important for politicians.
15. When solving problems, the key thing is knowing the methods for addressing each particular type of question. Understanding the "big ideas" might be helpful for specially-written problems, but not for most regular problems.
16. Given enough time, almost everybody could learn to think more scientifically, if they really wanted to.
17. To understand chemistry and physics, the formulas (equations) are really the main thing; the other material is mostly to help you decide which equations to use in which situations.
18. If someone is trying to learn physics, is the following a good kind of question to think about? Two students want to break a rope. Is it better for them to (1) grab opposite ends of the rope and pull (like in tug-of-war), or (2) tie one end of the rope to a wall and both pull on the other end together?
19. Scientists are having trouble predicting and explaining the behavior of thunder storms. This could be because thunder storms behave according to a very complicated or hard-to-apply set of rules. Or, that could be because some thunder storms don't behave consistently according to *any* set of rules, no matter how complicated and complete that set of rules is. In general, why do scientists sometimes have trouble explaining things? Please read all options before choosing one.
20. In chemistry, how do the most important formulas relate to the most important concepts? Please read all choices before picking one.
21. To be successful at *most things in life*...
22. To be successful at *science*...
23. Of the following test formats, which is best for measuring how well students understand the material in chemistry? Please read each choice before picking one.
24. **Brandon**: A good science textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each topic as a separate "unit," because they're not really separate. **Jamal**: But most of the time, each chapter is about a different topic, and those different topics don't always have much to do with each other. The textbook should keep everything separate, instead of blending it all together. With whom do you agree? Read all the choices before circling one.

25.
Anna: I just read about Kay Kinoshita, the physicist. She sounds naturally brilliant.
Emily: Maybe she is. But when it comes to being good at science, hard work is more important than “natural ability.” I bet Dr. Kinoshita does well because she has worked really hard.
Anna: Well, maybe she did. But let’s face it, some people are just smarter at science than other people. Without natural ability, hard work won’t get you anywhere in science!
26.
Justin: When I’m learning science concepts for a test, I like to put things in my own words, so that they make sense to me.
Dave: But putting things in your own words doesn't help you learn. The textbook was written by people who know science really well. You should learn things the way the textbook presents them.
27.
Julia: I like the way science explains how things I see in the real world.
Carla: I know that’s what we’re “supposed” to think, and it’s true for many things. But let’s face it, the science that explains things we do in lab at school can’t really explain earthquakes, for instance. Scientific laws work well in some situations but not in most situations.
Julia: I still think science applies to almost all real-world experiences. If we can’t figure out how, it’s because the stuff is very complicated, or because we don’t know enough science yet.
28.
Leticia: Some scientists think the dinosaurs died out because of volcanic eruptions, and others think they died out because an asteroid hit the Earth. Why can’t the scientists agree?
Nisha: Maybe the evidence supports both theories. There’s often more than one way to interpret the facts. So we have to figure out what the facts mean.
Leticia: I’m not so sure. In stuff like personal relationships or poetry, things can be ambiguous. But in science, the facts should speak for themselves.
29.
Jose: In my opinion, science is a little like fashion; something that’s “in” one year can be “out” the next. Scientists regularly change their theories back and forth.
Miguel: I have a different opinion. Once experiments have been done and a theory has been made to explain those experiments, the matter is pretty much settled.
There’s little room for argument.
30.
Jessica and Mia are working on a chemistry homework assignment together...
Jessica: O.K., we just got problem #1. I think we should go on to problem #2.
Mia: No, wait. I think we should try to figure out why the thing takes so long to reach the ground.
Jessica: Mia, we know it’s the right answer from the back of the book, so what are you worried about? If we didn’t understand it, we wouldn’t have gotten the right answer.
Mia: No, I think it’s possible to get the right answer without really understanding what it means.

Table 4-1: EBAPS Survey Items

The authors of the EBAPS questionnaire provide a template which scores each coded question from 0.0 (least sophisticated) to 4.0 (most sophisticated) (Elby, 2001; Ornek, 2015). The original study used a non-linear scoring so different questions were scored differently. For example, in some items, “strongly agree” represented the most sophisticated epistemology so it was given a score of 4.0 but in a different question, “strongly agree” represented the least sophisticated epistemology and was given a score of zero. The neutral option (option “C”) was sometimes given a score of “2.0”, but other items scored as “1.5” or “2.5” (White et al., 1999). The rationale for this choice was sometimes choosing “neutral” was a more or less sophisticated answer for certain questions.

In the current study, I transformed the scoring used by White et al., (1999) prior to data analysis as shown in Table 4.2. The items were scored from 1 (least sophisticated) to 5 (most sophisticated) with 1-point intervals. Since zero does not mean zero level of epistemological view, zero was avoided during statistical analysis. With ordinal data, it is inherent that the difference between the values of 1 and 2 may not be the same as the difference between 4 and 5 which is why I chose not to use 0.5 increments in my scoring, as modelled by White et al., 1999. Table 4.2 summarizes the difference in scoring between White et al., 1999 and the current study

Rating of response choices	**Scoring**	
	White et al., (1999)	**This Study**
Least sophisticated	0.0	1
Somewhat un- sophisticated	1.0	2
Neutral	1.5, 2.0 OR 2.5	3
Somewhat sophisticated	3.0	4
Most sophisticated	4.0	5

Table 4-2: Questionnaire Scoring

Changes to the scoring still yielded equivalent results, as represented by the Cronbach alpha value. Cronbach's alpha is a common measure of a questionnaire’s internal consistency (a measure of reliability). It is used to determine the extent the items in a factor are measuring the same underlying dimension by considering the mean inter-item covariance (Cortina, 1993). A reliability coefficient (α) of 0.70 or higher is considered acceptable (Anderson & Nashon, 2007; Peterson, 1994). However, Cronbach alpha depends on the number of items in each factor. A low

Cronbach alpha may just reflect lower items in the dimension (Cortina, 1993). Cortina (1993) concluded that if a scale has enough items (i.e., more than 20), then it can have an alpha of greater than .70 even when the correlation among items is very small. Nunnally (1978) is cited in many current studies in support of using reliability coefficient (α) of 0.70 (Peterson, 1994). However, Nunnally changed his reliability recommendations from his 1967 edition of Psychometric Theory in his 1978 edition. In 1967, he recommended that the minimally acceptable reliability for preliminary research should be in the range of 0.5 to 0.6; whereas in 1978 he increased the recommended level to 0.7 (without explanation) (Peterson, 1994).

The Cronbach alpha for the questionnaire in this study was 0.71 which is consistent with 0.70 that was reported in another study which used the original scoring (Keen-Rocha, 2008). Overall scores are the average scores of the means of all 30 items.

4.2 Analysis 1: Descriptive Statistics and One-way Repeated Measures ANOVA

The first analysis of the data examined whether the students as a single unit changed over time. The statistical software SPSS version 24 was used to perform descriptive analysis and a one-way repeated measures ANOVA. During the 11-month Vantage program, survey data were collected from the students three times- at the start of the program, after two terms in the program, and at the end of the third term ($Round_{SEPT}$, $Round_{MAY}$, $Round_{JULY}$). All students in the program were invited to participate for each round but not all students chose to complete the survey. Thus, the one-way repeated measures ANOVA was run for only those students who completed the survey in all the three rounds (N = 48). Table 4.3 presents the descriptive statistics of these data, which include the means, standard deviations and standard error.

Time	***N***	**Mean**	**Standard Deviation**	**Mean Standard Error**
$Round_{SEPT}$	75	3.40	0.29	0.03
$Round_{MAY}$	66	3.29	0.29	0.04
$Round_{JULY}$	53	3.29	0.34	0.05

Table 4-3: Descriptive Statistics for Three Rounds of Questionnaire Data

The mean score is the average of the mean scores of all the items in the EBAPS survey. The mean score was similar between $Round_{MAY}$ and $Round_{JULY}$ but was slightly different at $Round_{SEPT}$.

A one-way repeated measures ANOVA was used to examine whether there were any significant differences in the mean scores on the EBAPS questionnaire over time for students who completed the questionnaire for all three rounds ($N= 48$). In order to run the one-way repeated ANOVA test, we made assumptions of normality and sphericity in the data set. The assumption of normality was tested using the Shapiro-Wilks's test. The data were normally distributed at each round, as assessed by Shapiro-Wilk's test ($p > 0.05$). Kurtosis and Skewness are also measures of normality; each of which should fall within +/-1 for the assumption of normality to be valid. This is also the case for all three rounds. Mauchly's test of sphericity indicated that the assumption of sphericity has not been violated, $\chi^2(2) = 2.695$, $p = 0.260$.

The one-way repeated measures ANOVA indicate a significant difference between the mean overall epistemology scores, $F(2,94)=4.137$, $p <0.05$, partial $\eta^2 =0.081$. However, the Eta squared indicated a very small effect size (Cohen, 1992). Table 4.4 provides the results of the Bonferroni post-hoc test, which determined the differences. The Bonferroni post-hoc indicates that there was a statistically significant difference between the means $Round_{SEPT}$ and $Round_{JULY}$ ($p = 0.05$) while there is no statistically significant difference between $Round_{SEPT}$ and $Round_{MAY}$ or $Round_{MAY}$ and $Round_{JULY}$.

Survey Round (i)	Survey Round (j)	Mean Difference (i-j)	Std. Error	Significance
$Round_{SEPT}$	$Round_{MAY}$	0.108	0.049	$p = 0.1$
$Round_{SEPT}$	$Round_{JULY}$	0.133	0.054	$p = 0.05$
$Round_{MAY}$	$Round_{JULY}$	0.024	0.044	$p = 1.0$

Table 4-4: Overall Scores Pairwise Comparisons Bonferroni Post-hoc

4.2.1 Key Finding 1: Implications of Repeated Measures

The mean scores on the epistemological instrument indicate a difference between the overall scores from $Round_{SEPT}$ and $Round_{MAY/JULY}$. One-way repeated measures ANOVA indicates that the overall mean scores are significantly different between $Round_{SEPT}$ and $Round_{JULY}$ ($p = 0.05$). This indicates that students experienced some change in epistemologies over time.

4.3 Analysis II: Emergent Aspects (Factors) of Student Epistemologies

The second analysis of the data examined dominant factors underlying the students' responses to the items on the EBAPS, interpreted as a description of the key aspects of student epistemologies, and how the dominant aspects of their epistemologies changed over time. The authors of the EBAPS instrument claim that the instrument consists of five epistemological aspects or dimensions (White et al., 1999), which I will refer to as $Model_{EBAPS}$. Studies using the EBAPS instrument have assumed that these five epistemological dimensions are valid for various student populations (Elby, 2001; Ornek, 2015; Pulmones, 2010; Yildiran et al., 2011). To examine the validity of $\text{Model}_{\text{EBAPS}}$ for the population studied in this thesis, I performed confirmatory factor analysis (CFA) of $\text{Model}_{\text{EBAPS}}$ on each round ($\text{Round}_{\text{SEPT}}$, $\text{Round}_{\text{MAY}}$, $\text{Round}_{\text{JULY}}$) using AMOS version 24. Confirmatory factor analysis can be used to determine if the dimensions or factors of an established theory hold up to a dataset (Henson & Roberts, 2006). I then used SPSS and AMOS versions 24 and performed a combination of exploratory and confirmatory factor analyses for each round. Exploratory factor analysis (EFA) can be used to see what factors emerge from actual data set (Johnson & Stevens, 2001). This process led to three models, consisting of different dimensions ($\text{Model}_{\text{SEPT,}}$ $\text{Model}_{\text{MAY}}$ and $\text{Model}_{\text{JULY}}$). In order to determine how a model changed over time, confirmatory factor analysis (CFA) was performed for each model on subsequent rounds. CFA can also be readily used to test multiple models to view which model is the best fit over time (Thompson & Daniel, 1996). The process used here is similar to Johnson and Stevens (2001). The models were also tested using one-way repeated measuring ANOVA for triangulation.

4.3.1 Confirmatory Factor Analysis of $\text{Model}_{\text{EBAPS}}$

The authors of the EBAPS use the following factor model specified in Table 4.5 (Louca et al., 2004; White et al., 1999):

Factor Name	**Items**
Structure of scientific knowledge	2, 8, 10, 15, 17, 20, 23, 24
Nature of knowing and learning	1, 7, 11, 12, 13, 18, 26, 30
Real-life applicability	3, 14, 19, 27
Evolving knowledge	6, 28, 29
Source of ability to learn	5, 9, 16, 22, 25

Table 4-5: EBAPS Factors According to White et al., 1999

This model, Model$_{EBAPS}$ was tested using SPSS AMOS for the responses from Round$_{SEPT}$, Round$_{MAY}$, Round$_{JULY}$ (Figure 4.1). In all analyses, item 2 had a significant standard error which, at times, led to an incomplete analysis. During the one-on-one interviews, students were questioned about how they answered item 2 and two out of 13 students interviewed stated that they did not interpret the item correctly. They understood the question to say, "...remembering facts IS very important" instead of "remembering facts isn't very important". The other 11 students interviewed remembered interpreting the question as it was intended. When an error message was received during CFA, item 2 was removed and the model was re-evaluated.

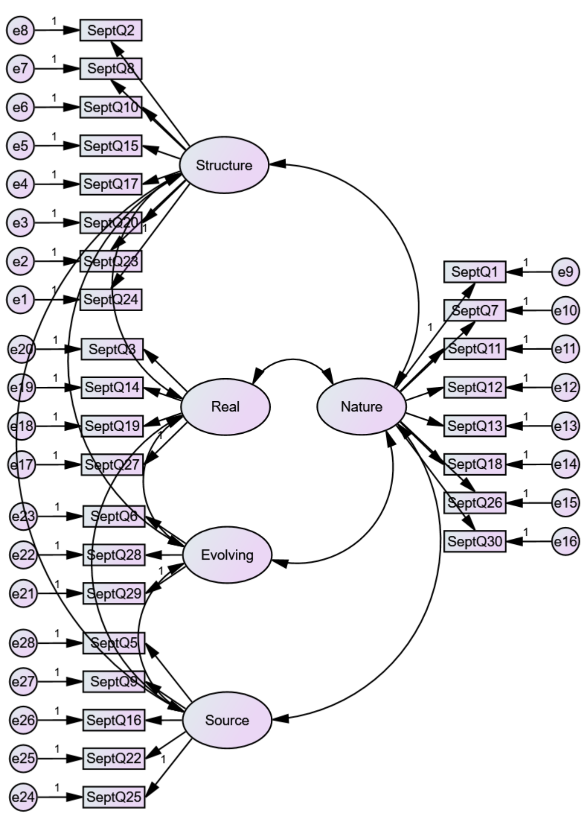

Figure 4-1: Factor Structure of Model(EBAPS) Created in AMOS Version 24

As discussed in Section 3.8, to evaluate a model's goodness of fit, several indices can be used. In the current study we used CMIN/df and CFI. A CMIN/df less than 5 with $p > 0.5$ indicates a permissible fit (Hu & Bentler, 1999). CFI ranges from 0 to 1.0, with larger values (>0.7) indicating a good fit (Furr & Bacharach, 2013).

As shown in Table 4.6, $Model_{EBAPS}$ was not a permissible fit, as indicated by $p < 0.05$ for CMIN/df for all three rounds and low CFI values. In order to determine if some factors from $Model_{EBAPS}$ were present in the population, Figure 4-2 provides the unstandardized regression estimates of items from CFA using $Model_{EBAPS}$ on $Round_{SEPT}$ responses. Large standard errors suggest that that factor is not dominant in the dataset. Figure 4-2 indicates that only dimensions "Real-life applicability" and "Source of the ability to learn" may be dominant for the population studied in this thesis.

Round	**DF**	**CMIN**	**CMIN/df**	***p-value***	**CFI**
$Round_{SEPT}$	350	486	1.389	0.00	0.268
$Round_{MAY}$	340	497	1.463	0.00	0.409
$Round_{JULY}$	340	549	1.616	0.00	0.392

Table 4-6: Model (EBAPS) Goodness of Fit

			Estimate	S.E.
SeptQ24	<---	Structure	1.000	
SeptQ23	<---	Structure	-.738	6.841
SeptQ20	<---	Structure	10.186	60.085
SeptQ17	<---	Structure	14.227	83.782
SeptQ15	<---	Structure	6.352	37.608
SeptQ10	<---	Structure	8.913	52.656
SeptQ8	<---	Structure	10.978	64.690
SeptQ2	<---	Structure	-6.943	41.013
SeptQ1	<---	Nature	1.000	
SeptQ7	<---	Nature	.362	.726
SeptQ11	<---	Nature	-.554	.684
SeptQ12	<---	Nature	.496	.517
SeptQ13	<---	Nature	-.441	.703
SeptQ18	<---	Nature	2.022	1.268
SeptQ26	<---	Nature	3.126	1.969
SeptQ30	<---	Nature	2.035	1.343
SeptQ27	<---	Real	1.000	
SeptQ19	<---	Real	-.086	.352
SeptQ14	<---	Real	-.369	.480
SeptQ3	<---	Real	.489	.651
SeptQ29	<---	Evolving	1.000	
SeptQ28	<---	Evolving	-1.129	2.062
SeptQ6	<---	Evolving	-1.004	1.815
SeptQ25	<---	Source	1.000	
SeptQ22	<---	Source	1.255	.435
SeptQ16	<---	Source	.402	.221
SeptQ9	<---	Source	.636	.211
SeptQ5	<---	Source	.025	.197

Figure 4-2: Unstandardized Regression Estimates from CFA Using Model (EBAPS) on Round (SEPT)

The lack of permissible fit of Model$_{EBAPS}$ may be the result of a population difference between the current study and the research from White et al., (1999). Model$_{EBAPS}$ was confirmed using data from students drawn from six separate community colleges in northern California. These subjects were ethnically and socioeconomically diverse (White et al., 1999). The students of the current study are international students, English language learners, as well as learners of North American academic culture. The CFI values indicate that the goodness of fit of $Model_{EBAPS}$ improves after $Round_{SEPT}$ (Table 4-6). Participants of the current study would have been least comfortable with English and any cultural references in $Round_{SEPT}$. In fact, during the interviews students identified that they did not understand terms such as, “everything is up in the air!” from item 6. It is possible that if this study continued for a longer period, the population would have reflected similar factors as White et al., (1999) because their English language skills would have improved as well as their familiarity with North American English expressions.

4.3.2 Key Finding 2: $Model_{EBAPS}$ is Not a Permissible Fit.

Although $Model_{EBAPS}$ has been applied by other studies (Elby, 2001; Ornek, 2015; Pulmones, 2010; Yildiran et al., 2011), confirmatory factor analysis indicates that this model is not a permissible fit for the population in this study. I will now proceed to use exploratory factor analysis to determine the aspects of epistemology that emerged from this study’s dataset.

4.3.3 Exploratory Factor Analysis of $Round_{SEPT}$, $Round_{MAY}$, and $Round_{JULY}$

To investigate the underlying factor structure at different times ($Round_{SEPT}$, $Round_{MAY}$ and $Round_{JULY}$), exploratory factor analysis using SPSS version 24 was performed. The suitability of factor analysis was assessed prior to analysis. Inspection of the correlation matrix showed that all variables had at least one correlation coefficient greater than 0.3. The overall Kaiser-Meyer-Olkin (KMO) measure was 0.471 for $Round_{SEPT}$ and $Round_{MAY}$ (Furr & Bacharach, 2013). For $Round_{JULY}$ KMO is 0.336 (<0.5) and N =53, which indicates that exploratory factor analysis may not yield reliable results for this dataset. We still proceeded with

EFA for $Round_{JULY}$ to use as a potential guide for analyzing the qualitative data but proceeded cautiously when making any conclusions. Bartlett's Test of Sphericity was statistically significant ($p < 0.05$), indicating that the data was likely factorable. As identified in section 3.8, I applied four criteria when performing EFA and this led to three different factor structures- $Model_{SEPT}$, $Model_{MAY}$, $Model_{JULY}$. Tables 4.7 and 4.8 provide details of the models.

Round	Model	Number of factors	%Variance explained	Cronbach Alpha*
$Round_{SEPT}$	$Model_{SEPT}$	5	41.3	0.575
$Round_{MAY}$	$Model_{MAY}$	5	43.4	0.650
$Round_{JULY}$	$Model_{JULY}$	4	40.3	0.724

Table 4-7: Results from EFA

*removing Q2 due to high standard errors.

Model	Items in Factors				
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
$Model_{SEPT}$	9, 16, 21, 22, 23, 25, 29	1, 4, 6, 10, 14, 18, 19, 26, 30	7, 12, 28,	2, 3, 5, 11, 20, 24, 27	8, 13, 15, 17
$Model_{MAY}$	1,6,7,21,22, 23,29	2,5,9,11,12,16, 19,26,27,30	8,14,20,24,25,	3,10,17	4,13,15,18
$Model_{July}$	1,2,5,10,12,14,15, 17,19,20,26,30	9,16,21,22,23, 24,25,27,29.	3,6,7,8,11	4,13,18,25,28	N/A

Table 4-8: Items in Factors for the Three Models. Colored cells Indicate Similarity between Factors Across Models.

For each model, I studied the items in each factor and looked for patterns. For factors with a large number of items (> 6), I first focused on the items with the largest loadings to help identify the factor (Gie Yong & Pearce, 2013). As detailed in section 3.6, I acknowledge that in this type of process, the findings will be influenced by my own personal experiences, which led to one of my thesis supervisors, Dr. Samson Nashon to serve as a separate auditor of my interpretations. Table 4.9 summarizes the conceptual meanings of the factors from all three rounds. I will now discuss each model in detail.

Conceptual Interpretations of the Factors		
$Model_{SEPT}$	$Model_{MAY}$	$Model_{JULY}$
1. Success in science as a function of hard work or natural ability 2. Authorities in Science 3. Confidence in understanding science 4. Absolutism in Science 5. Learning Science in the Classroom	1. Multiple Perspectives about success in Science 2. Doing well in Science 3. Awareness of the Structure of Scientific Knowledge (Pieces vs whole) 4. Awareness of the complexity in Science 5. Problem-solving in Science	1. Doing well in Science 2. Success in science as a function of hard work or natural ability 3. Awareness of Self in Science 4. Learning about Science

Table 4-9: Conceptual Meanings of Factors Determined by EFA

4.3.4 Factor Structure of $Model_{SEPT}$

The scree plot (Figure 4.3) suggests up to 7 factors before an inflection point. However, to be retained for further analysis, each factor should have had at least three items with loadings greater than 0.20 and these items should measure the same construct (Tabachnik & Fidell, 2001). Based on this criteria, 5 factors were identified and Figure 4.4 shows the items and their loadings for each factor. These five factors accounted for 41% of the total variance of the scores (Figure 4.5). This means that 41% of the total variance of students scored on the items that loaded on the initial factors can be explained in terms of the conceptual interpretation assigned to the first five factors.

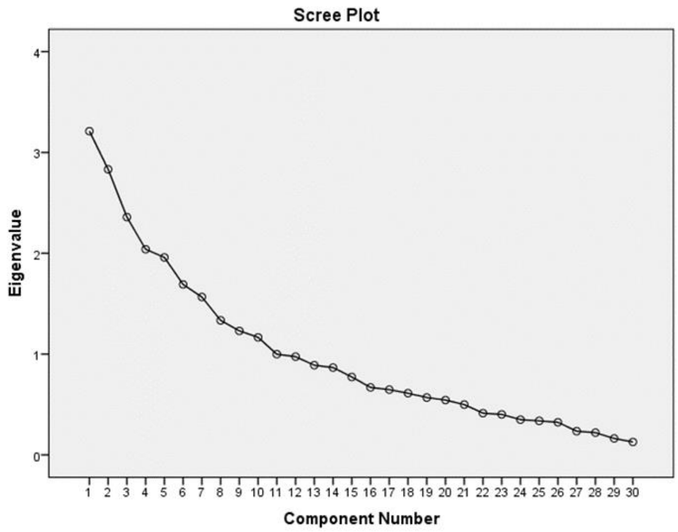

Figure 4-3: Scree Plot for Factor Analysis of Round (SEPT)

The items and their loadings are given in Figure 4.4:

	Component				
	1	2	3	4	5
SeptQ22	.813	.062	-.134	-.141	.099
SeptQ25	.693	-.064	.189	-.041	.212
SeptQ21	.608	-.181	-.075	-.309	-.164
SeptQ9	.598	.049	.341	.060	.080
SeptQ16	.448	.187	.010	.236	-.403
SeptQ23	.236	-.026	-.451	.088	-.345
SeptQ29	.338	-.079	-.361	.078	.192
SeptQ4	-.301	.200	.053	-.154	.196
SeptQ18	-.073	.668	-.080	.027	-.175
SeptQ10	.079	.578	-.302	-.129	.298
SeptQ30	-.172	.542	.398	-.155	.137
SeptQ26	-.020	.519	-.005	-.025	-.480
SeptQ1	-.182	.479	.040	-.080	.228
SeptQ19	.015	.448	.090	.169	-.175
SeptQ14	.175	.439	.319	-.013	.144
SeptQ6	-.019	.316	-.018	-.012	.002
SeptQ28	.133	-.181	.656	-.079	.122
SeptQ12	-.159	.161	.615	.374	-.079
SeptQ7	.203	.115	.506	.046	-.157
SeptQ11	-.053	-.197	.029	.650	-.132
SeptQ20	-.063	.211	-.070	.629	.097
SeptQ27	-.150	-.018	-.346	.545	.046
SeptQ5	.020	-.011	.335	.473	.175
SeptQ3	.175	-.109	.269	.472	.215
SeptQ2	-.158	-.255	-.237	-.408	-.018
SeptQ24	-.023	-.046	-.030	.250	-.094
SeptQ13	.185	-.037	.114	-.223	.633
SeptQ17	.084	.072	-.255	.357	.543
SeptQ15	-.018	.098	.013	.104	.494
SeptQ8	.225	.461	.305	.165	.322

Figure 4-4: Factor Loadings for Round(SEPT)

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.211	10.703	10.703	3.211	10.703	10.703	2.696	8.987	8.987
2	2.832	9.441	20.143	2.832	9.441	20.143	2.654	8.848	17.834
3	2.358	7.862	28.005	2.358	7.862	28.005	2.483	8.276	26.111
4	2.040	6.798	34.803	2.040	6.798	34.803	2.446	8.154	34.264
5	1.959	6.529	41.332	1.959	6.529	41.332	2.120	7.068	41.332
6	1.690	5.634	46.967						
7	1.566	5.221	52.188						
8	1.334	4.448	56.636						
9	1.230	4.101	60.737						
10	1.166	3.886	64.623						
11	.999	3.329	67.952						
12	.974	3.247	71.200						
13	.889	2.965	74.164						
14	.866	2.888	77.052						
15	.772	2.575	79.627						
16	.669	2.230	81.856						
17	.647	2.157	84.013						
18	.611	2.038	86.051						
19	.569	1.896	87.948						
20	.544	1.812	89.760						
21	.499	1.664	91.424						
22	.414	1.379	92.803						
23	.402	1.338	94.141						
24	.350	1.166	95.307						
25	.338	1.126	96.433						
26	.323	1.077	97.510						
27	.235	.784	98.293						
28	.221	.736	99.029						
29	.163	.544	99.573						
30	.128	.427	100.000						

Figure 4-5: Round(SEPT) Extracted Factors and % Variance Accounted for by the Factors

The items loaded onto each of the five factors are provided in the tables, along with the conceptual meanings of the items grouped into the same factor. When appropriate, the three items that contain the largest loadings for a factor are indicated in bold.

Factor 1: Success in science using hard work or natural ability
9. Someone who doesn't have high natural ability can still learn the material well even in a hard chemistry or physics class. 16. Given enough time, almost everybody could learn to think more scientifically, if they really wanted to. 21. **To be successful at *most things in life*...** 22**. To be successful at *science*...** 23. Of the following test formats, which is best for measuring how well students understand the material in chemistry? Please read each choice before picking one. 25. **Anna: I just read about Kay Kinoshita, the physicist. She sounds naturally brilliant.** **Emily: Maybe she is. But when it comes to being good at science, hard work is more important than "natural ability." I bet Dr. Kinoshita does well because she has worked really hard.** **Anna: Well, maybe she did. But let's face it, some people are just smarter at science than other people. Without natural ability, hard work won't get you anywhere in science!** 29. Jose: In my opinion, science is a little like fashion; something that's "in" one year can be "out" the next. Scientists regularly change their theories back and forth. Miguel: I have a different opinion. Once experiments have been done and a theory has been made to explain those experiments, the matter is pretty much settled. There's little room for argument.

Table 4-10: Factor 1 of Model (SEPT). Items in Bold Have the Largest Factor Loadings.

Extracting the items that loaded onto factor 1 and carefully considering the meaning of what these items convey (Table 4.10), I find them pointing towards succeeding in science. A number of the items are about hard work and natural ability which is a dimension, labelled as "Source of the ability to learn" in Model$_{EBAPS}$ (White et al., 1999). This dimension was indicated by CFA to be persistent (Section 4.3.1). Hence, I interpreted and described Factor 1 as "Success in science as a function of hard work or natural ability".

Table 4.11 shows the items for Factor 2. I find these items related to authoritative sources of science knowledge since many of the items refer to a textbook, a student or a scientist as an authority of science knowledge. The conceptual underpinning of this factor is similar to Schommer's dimension, "source of knowledge" which looks at how individuals view the role of external and internal sources of knowledge (Schommer, 1993a).

Factor 2: Authoritative sources of science knowledge
1.Tamara just read something in her science textbook that seems to disagree with her own experiences. But to learn science well, Tamara shouldn't think about her own experiences; she should just focus on what the book says. 4. When it comes to science, most students either learn things quickly, or not at all. 6. When it comes to controversial topics such as which foods cause cancer, there's no way for scientists to evaluate which scientific studies are the best. Everything's up in the air! 10. **Often, a scientific principle or theory just doesn't make sense. In those cases, you have to accept it and move on, because not everything in science is supposed to make sense.** 14. Understanding science is really important for people who design rockets, but not important for politicians. 18. **If someone is trying to learn physics, is the following a good kind of question to think about? Two students want to break a rope. Is it better for them to (1) grab opposite ends of the rope and pull (like in tug-of-war), or (2) tie one end of the rope to a wall and both pull on the other end together?** 19. Scientists are having trouble predicting and explaining the behavior of thunder storms. This could be because thunder storms behave according to a very complicated or hard-to-apply set of rules. Or, that could be because some thunder storms don't behave consistently according to *any* set of rules, no matter how complicated and complete that set of rules is. In general, why do scientists sometimes have trouble explaining things? Please read all options before choosing one. 26. Justin: When I'm learning science concepts for a test, I like to put things in my own words, so that they make sense to me. Dave: But putting things in your own words doesn't help you learn. The textbook was written by people who know science really well. You should learn things the way the textbook presents them. 30. **Jessica and Mia are working on a chemistry homework assignment together...** **Jessica: O.K., we just got problem #1. I think we should go on to problem #2.** **Mia: No, wait. I think we should try to figure out why the thing takes so long to reach the ground.** **Jessica: Mia, we know it's the right answer from the back of the book, so what are you worried about? If we didn't understand it, we wouldn't have gotten the right answer.** **Mia: No, I think it's possible to get the right answer without really understanding what it means.**

Table 4-11: Factor 2 of Model (SEPT). Items in Bold Have the Largest Factor Loadings.

All three of the items in Factor 3 are referring to understanding in science (Table 4.12); whether it is understanding established scientific theories or new scientific evidence. There is also an underlying theme of confidence; the teacher seems to become more confident after she or he teaches, an individual must be confident in their own ideas in order to relate them to new science content, and scientists must have confidence in their theories to defend them if a colleague disagrees. Thus, I describe and interpret Factor 3 to be "confidence in understanding science".

Factor 3: Confidence in understanding science
7. A teacher once said, “I don’t *really* understand something until I teach it.” But actually, teaching doesn’t help a teacher understand the material better; it just reminds her of how much he or she already knows. 12. When learning science, people can understand the material better if they relate it to their own ideas. 28. Leticia: Some scientists think the dinosaurs died out because of volcanic eruptions, and others think they died out because an asteroid hit the Earth. Why can’t the scientists agree? Nisha: Maybe the evidence supports both theories. There’s often more than one way to interpret the facts. So we have to figure out what the facts mean. Leticia: I’m not so sure. In stuff like personal relationships or poetry, things can be ambiguous. But in science, the facts should speak for themselves.

Table 4-12: Factor 3 of Model (SEPT)

Table 4.13 contains the items for Factor 4. I interpreted and describe this factor to be “Absolutism in Science”. Many of the items have an underlying theme with the questions, ‘Is scientific knowledge right/wrong like a test or made of rules like facts and formulas?’ or ‘Is there uncertainty in science? This factor is related to the factor, “Evolving knowledge” in Model$_{EBAPS}$ since both are pointing towards absolutism. However, the factor in Model$_{EBAPS}$ is looking at evolution of scientific knowledge, Factor 4 in Model$_{SEPT}$ seems to be a step before considering how scientific knowledge evolves. That is, to first consider there are limitations in science.

Factor 4: Absolutism in Science
2. When it comes to understanding physics or chemistry, remembering facts isn't very important. 3.Obviously, computer simulations can predict the behavior of physical objects like comets. But simulations can also help scientists estimate things involving the behavior of *people*, such as how many people will buy new television sets next year. 5. If someone is having trouble in physics or chemistry class, studying in a better way can make a big difference. 11. **When handing in a physics or chemistry test, you can generally have a sense of well you did even before talking about it with other students.** 20. **In chemistry, how do the most important formulas relate to the most important concepts? Please read all choices before picking one.** 24. Brandon: A good science textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each topic as a separate "unit," because they're not really separate. Jamal: But most of the time, each chapter is about a different topic, and those different topics don't always have much to do with each other. The textbook should keep everything separate, instead of blending it all together. With whom do you agree? Read all the choices before circling one. 27. **Julia: I like the way science explains how things I see in the real world.** **Carla: I know that's what we're "supposed" to think, and it's true for many things. But let's face it, the science that explains things we do in lab at school can't really explain earthquakes, for instance. Scientific laws work well in some situations but not in most situations.** **Julia: I still think science applies to almost all real-world experiences. If we can't figure out how, it's because the stuff is very complicated, or because we don't know enough science yet.**

Table 4-13: Factor 4 of Model (SEPT). Items in Bold Have the Largest Factor Loadings.

The pattern among items in Factor 5 (Table 4.14) is consistent with one of the learning goals identified by Hodson (2014), Learning science. Hodson (2014) defines this as acquiring knowledge. For example, the items refer to clear lectures or methods to solve problems or memorizing formulas. Since the items are referring to classroom context, I labelled this factor, "Learning Science in the Classroom".

Factor 5: Learning Science in the Classroom
8. Scientists should spend almost all their time gathering information. Worrying about theories can't really help us understand anything. 13. If physics and chemistry teachers gave *really clear* lectures, with plenty of real-life examples and sample problems, then most good students could learn those subjects without doing lots of sample questions and practice problems on their own. 15. When solving problems, the key thing is knowing the methods for addressing each particular type of question. Understanding the "big ideas" might be helpful for specially-written problems, but not for most regular problems. 17. To understand chemistry and physics, the formulas (equations) are really the main thing; the other material is mostly to help you decide which equations to use in which situations.

Table 4-14: Factor 5 of Model (SEPT)

4.3.4.1 Reliability of Factor Structure of Model$_{SEPT}$

Table 4.15 provides the Cronbach alpha scores for each factor, along with the number of items in each factor. Although the values are lower than 0.7, they are above the acceptable limit of 0.5 identified in Nunnally (1967). It is apparent that the factors with lower items have lower Cronbach alpha scores (Cortina, 1993). Moreover, we retained the factors because of the strong qualitative (Chapter 5) and theoretical validity (Nashon & Madera, 2013).

Factor	Name Given to Factor	Number of Items	Cronbach Alpha
1	Success in science using hard work or natural ability	7	0.605
2	Authorities of science knowledge	9	0.617
3	Confidence in understanding science	3	0.511
4	Absolutism in Science	6	0.514* (remove item 2)
5	Learning Science in the Classroom	4	0.532

Table 4-15: Cronbach Alpha Scores for Factors of Model (SEPT)

4.3.4.2 Confirmatory Factor Analysis of Model$_{SEPT}$

When confirmatory factor analysis is used to test a model determined through EFA, it must be run on a separate data set (Justicia et al., 2008). Moreover, this study is looking at change over time so CFA was used to confirm Model$_{SEPT}$ on subsequent rounds (Round$_{MAY}$ and Round$_{JULY}$). Model$_{SEPT}$ is not a permissible fit for the other rounds as indicated by CMIN/df and $p < 0.05$ (Table 4.16). The CFI value is less than 0.7, also indicates that Model$_{SEPT}$ is not a permissible fit for the other rounds.

	Goodness of Fit (CMIN/df, p-value, CFI)
$Round_{SEPT}$	N/A
$Round_{MAY}$	1.463, $p < 0.05$ CFI = 0.395
$Round_{JULY}$	1.755, $p < 0.05$ CFI = 0.320

Table 4-16: Goodness of Fit of Model (SEPT) on Round (MAY) and Round (July)

Figure 4-6 provides the unstandardized regression estimates of items from CFA using $Model_{SEPT}$ on $Round_{MAY}$ responses. The standard errors are consistently high for items in the factor, "Absolutism in Science" which suggests that this factor was not dominant in $Round_{MAY}$. The other factors have one or two items with higher standard errors which suggests that those items should be removed but the factor is still persistent.

Item		Factor	Estimate	S.E.
MayQ29	<---	SciSuccess	1.000	
MayQ25	<---	SciSuccess	.187	.197
MayQ23	<---	SciSuccess	-.153	.216
MayQ22	<---	SciSuccess	.112	.229
MayQ21	<---	SciSuccess	.383	.237
MayQ16	<---	SciSuccess	.014	.169
MayQ9	<---	SciSuccess	157.086	5413.226
MayQ30	<---	Authorities	1.000	
MayQ26	<---	Authorities	1.185	.745
MayQ19	<---	Authorities	1.392	.955
MayQ18	<---	Authorities	.300	.373
MayQ14	<---	Authorities	2.233	1.199
MayQ10	<---	Authorities	1.487	.858
MayQ6	<---	Authorities	.983	.638
MayQ4	<---	Authorities	.887	.608
MayQ1	<---	Authorities	1.878	1.020
MayQ7	<---	Confidence	1.000	
MayQ12	<---	Confidence	-.218	.167
MayQ28	<---	Confidence	.116	.133
MayQ3	<---	Absolutism	1.000	
MayQ5	<---	Absolutism	4.540	4.969
MayQ11	<---	Absolutism	1.270	1.755
MayQ20	<---	Absolutism	5.497	6.107
MayQ24	<---	Absolutism	2.522	2.908
MayQ27	<---	Absolutism	2.945	3.387
MayQ8	<---	Learn	1.000	
MayQ13	<---	Learn	.303	.201
MayQ15	<---	Learn	.268	.175
MayQ17	<---	Learn	.272	.193

Figure 4-6: Unstandardized Regression Estimates from CFA using Model (SEPT) on Round (MAY)

Figure 4-7 provides the unstandardized regression estimates of items using $Model_{SEPT}$ on $Round_{JULY}$ responses. Although the standard errors are higher for items in the factor, “Success in Science using hard work or natural talent”, they are not significantly higher than the others. The other factors have one or two items with abnormal standard errors, which suggests that those items should be removed but the factor is still persistent. The factor “absolutism”, which was not dominant in $Round_{MAY}$ is again dominant in $Round_{JULY}$.

Item		Factor	Estimate	S.E.
JulyQ29	<---	SciSuccess	1.000	
JulyQ25	<---	SciSuccess	.606	.923
JulyQ23	<---	SciSuccess	-2.140	2.287
JulyQ22	<---	SciSuccess	.835	1.134
JulyQ21	<---	SciSuccess	.983	1.244
JulyQ16	<---	SciSuccess	2.422	2.510
JulyQ9	<---	SciSuccess	4.657	4.953
JulyQ30	<---	Authorities	1.000	
JulyQ26	<---	Authorities	.300	.486
JulyQ19	<---	Authorities	1.796	1.104
JulyQ18	<---	Authorities	.839	.561
JulyQ14	<---	Authorities	1.521	.877
JulyQ10	<---	Authorities	1.484	.845
JulyQ6	<---	Authorities	.697	.505
JulyQ4	<---	Authorities	.792	.528
JulyQ1	<---	Authorities	2.122	1.167
JulyQ7	<---	Confidence	1.000	
JulyQ12	<---	Confidence	.728	.293
JulyQ28	<---	Confidence	.521	.314
JulyQ3	<---	Absolutism	1.000	
JulyQ5	<---	Absolutism	.982	.430
JulyQ11	<---	Absolutism	.862	.385
JulyQ20	<---	Absolutism	1.187	.620
JulyQ24	<---	Absolutism	-.081	.452
JulyQ27	<---	Absolutism	.511	.411
JulyQ8	<---	Learn	1.000	
JulyQ13	<---	Learn	-.128	.250
JulyQ15	<---	Learn	.975	.288
JulyQ17	<---	Learn	.955	.292

Figure 4-7: Unstandardized Regression Estimates from CFA using Model (SEPT) on Round (JULY)

4.3.5 Factor Structure of Model$_{MAY}$

The Scree plot (Figure 4.8) suggests 4 or 5 factors before an inflection point. Applying the other criteria leaves us with 5 factors. These five factors account for 43.4% of the variance (Figure 4.9).

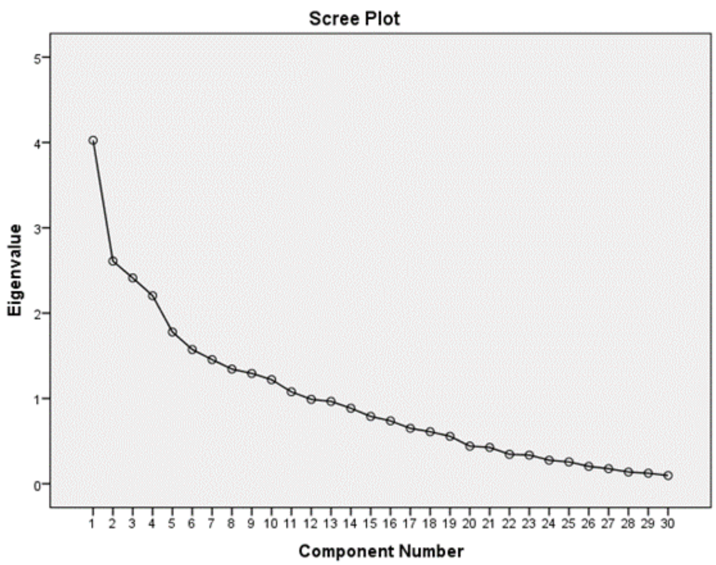

Figure 4-8: Scree Plot for Model(MAY)

	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.026	13.419	13.419	4.026	13.419	13.419	2.997	9.990	9.990
2	2.610	8.700	22.119	2.610	8.700	22.119	2.859	9.529	19.519
3	2.412	8.040	30.159	2.412	8.040	30.159	2.503	8.343	27.862
4	2.204	7.348	37.507	2.204	7.348	37.507	2.419	8.062	35.924
5	1.779	5.929	43.436	1.779	5.929	43.436	2.254	7.513	43.436
6	1.574	5.246	48.682						
7	1.455	4.850	53.533						
8	1.344	4.480	58.013						
9	1.293	4.311	62.323						
10	1.220	4.068	66.391						
11	1.078	3.592	69.983						
12	.989	3.298	73.281						
13	.965	3.218	76.500						
14	.885	2.950	79.450						
15	.790	2.633	82.083						
16	.737	2.458	84.540						
17	.650	2.167	86.708						
18	.610	2.034	88.741						
19	.556	1.855	90.596						
20	.441	1.470	92.066						
21	.426	1.421	93.488						
22	.345	1.151	94.639						
23	.336	1.121	95.760						
24	.276	.920	96.680						
25	.256	.854	97.534						
26	.204	.680	98.214						
27	.177	.589	98.803						
28	.138	.460	99.263						
29	.124	.415	99.677						
30	.097	.323	100.000						

Figure 4-9: % Variance of Model(MAY)

The items and their loadings are given in given in Figure 4.10.

	Component				
	1	2	3	4	5
MayQ21	.731	-.066	.011	-.195	-.045
MayQ6	.685	.052	-.058	.077	-.001
MayQ23	.189	.170	-.649	.063	.060
MayQ7	.641	-.175	.179	.347	.124
MayQ1	.441	.092	.427	.099	.144
MayQ29	.329	-.287	-.288	.023	-.244
MayQ22	.444	.024	.011	-.562	-.023
MayQ2	-.657	-.286	-.153	-.007	-.144
MayQ5	.143	.659	-.042	-.092	-.113;
MayQ26	.155	.608	.009	-.123	.234
MayQ11	-.200	.589	-.319	.201	-.225
MayQ27	-.015	.479	.077	.018	.031
MayQ30	-.070	.425	.153	.208	.066
MayQ19	.123	.408	.281	.124	-.258
MayQ16	.016	.359	-.203	-.345	-.051
MayQ28	-.022	.256	.292	-.324	.189
MayQ9	.047	.366	.057	-.300	-.583
MayQ12	.035	.291	.058	.142	-.485
MayQ24	.051	.033	.626	-.046	-.032
MayQ20	.251	.151	.578	.059	-.027
MayQ14	.511	.121	.547	-.099	.024
MayQ8	.246	.237	.338	.305	.331
MayQ25	-.006	-.011	.170	-.310	-.208
MayQ17	.086	.063	.010	.816	.019
MayQ3	.114	.128	-.272	.581	-.477
MayQ10	.153	.391	.261	.411	.202
MayQ4	-.077	.385	.145	-.128	.550
MayQ13	.260	.034	-.030	.058	.543
MayQ18	.046	.250	-.203	.052	.399
MayQ15	.029	.037	.196	.263	.386

Figure 4-10: Factor Loadings of Model(MAY)

The items loaded onto each of the five factors are provided in the following tables, along with the conceptual meanings of the items grouped into the same factor. When appropriate, the three items with the largest loadings in highlighted in bold.

Factor 1: Multiple perspectives about success in science
1.Tamara just read something in her science textbook that seems to disagree with her own experiences. But to learn science well, Tamara shouldn't think about her own experiences; she should just focus on what the book says. 6**. When it comes to controversial topics such as which foods cause cancer, there's no way for scientists to evaluate which scientific studies are the best. Everything's up in the air!** **7. A teacher once said, "I don't *really* understand something until I teach it." But actually, teaching doesn't help a teacher understand the material better; it just reminds her of how much he or she already knows.** 21. **To be successful at *most things in life*...** 22. To be successful at *science*... 23. Of the following test formats, which is best for measuring how well students understand the material in chemistry? Please read each choice before picking one. 29. Jose: In my opinion, science is a little like fashion; something that's "in" one year can be "out" the next. Scientists regularly change their theories back and forth. Miguel: I have a different opinion. Once experiments have been done and a theory has been made to explain those experiments, the matter is pretty much settled. There's little room for argument.

Table 4-17: Items for Factor 1 of Model (MAY)

Items in Factor 1 of $\text{Model}_{\text{MAY}}$ overlap with many items of Factor 1, "Being successful at science as a function of hard work or natural ability" of $\text{Model}_{\text{SEPT}}$ (Table 4.17). However, there was enough of a difference that Factor 1 of $\text{Model}_{\text{MAY}}$ was not given the same name; there is more focus on multiple perspectives in the items of this factor so it is titled, "Seeing multiple perspectives about success in science".

Many of the items in Factor 2 refer to strategies, such as re-phrasing concepts into your own words, for doing well in science (Table 4.18).

Factor 2: Doing well in Science
2. When it comes to understanding physics or chemistry, remembering facts isn't very important. 5. **If someone is having trouble in physics or chemistry class, studying in a better way can make a big difference.** 9. Someone who doesn't have high natural ability can still learn the material well even in a hard chemistry or physics class. 11. **When handing in a physics or chemistry test, you can generally have a sense of well you did even before talking about it with other students.** 12. When learning science, people can understand the material better if they relate it to their own ideas. 16. Given enough time, almost everybody could learn to think more scientifically, if they really wanted to. 19. Scientists are having trouble predicting and explaining the behavior of thunder storms. This could be because thunder storms behave according to a very complicated or hard-to-apply set of rules. Or, that could be because some thunder storms don't behave consistently according to *any* set of rules, no matter how complicated and complete that set of rules is. In general, why do scientists sometimes have trouble explaining things? Please read all options before choosing one. 26. **Justin: When I'm learning science concepts for a test, I like to put things in my own words, so that they make sense to me.** **Dave: But putting things in your own words doesn't help you learn. The textbook was written by people who know science really well. You should learn things the way the textbook presents them.** 27. Julia: I like the way science explains how things I see in the real world. Carla: I know that's what we're "supposed" to think, and it's true for many things. But let's face it, the science that explains things we do in lab at school can't really explain earthquakes, for instance. Scientific laws work well in some situations but not in most situations. Julia: I still think science applies to almost all real-world experiences. If we can't figure out how, it's because the stuff is very complicated, or because we don't know enough science yet. 30. Jessica and Mia are working on a chemistry homework assignment together... Jessica: O.K., we just got problem #1. I think we should go on to problem #2. Mia: No, wait. I think we should try to figure out why the thing takes so long to reach the ground. Jessica: Mia, we know it's the right answer from the back of the book, so what are you worried about? If we didn't understand it, we wouldn't have gotten the right answer. Mia: No, I think it's possible to get the right answer without really understanding what it means.

Table 4-18: Items for Factor 2 of Model (MAY)

The theme in Factor 3 refer to whether science is seen as a collection of disconnected facts or as a connected structure (Table 4.19). This idea is similar to the dimension, "Structure of Scientific Knowledge" from EBAPS (White et al., 1999) and the discussion put forth by diSessa, (1993).

Factor 3: Awareness of the Structure of Scientific Knowledge (Pieces vs whole)
8. Scientists should spend almost all their time gathering information. Worrying about theories can't really help us understand anything. 14. Understanding science is really important for people who design rockets, but not important for politicians. 20. In chemistry, how do the most important formulas relate to the most important concepts? Please read all choices before picking one. 24. Brandon: A good science textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each topic as a separate "unit," because they're not really separate. Jamal: But most of the time, each chapter is about a different topic, and those different topics don't always have much to do with each other. The textbook should keep everything separate, instead of blending it all together. With whom do you agree? Read all the choices before circling one. 25. Anna: I just read about Kay Kinoshita, the physicist. She sounds naturally brilliant. Emily: Maybe she is. But when it comes to being good at science, hard work is more important than "natural ability." I bet Dr. Kinoshita does well because she has worked really hard. Anna: Well, maybe she did. But let's face it, some people are just smarter at science than other people. Without natural ability, hard work won't get you anywhere in science! 28. Leticia: Some scientists think the dinosaurs died out because of volcanic eruptions, and others think they died out because an asteroid hit the Earth. Why can't the scientists agree? Nisha: Maybe the evidence supports both theories. There's often more than one way to interpret the facts. So we have to figure out what the facts mean. Leticia: I'm not so sure. In stuff like personal relationships or poetry, things can be ambiguous. But in science, the facts should speak for themselves.

Table 4-19: Items for Factor 3 of Model (MAY)

The items in Factor 4 indicate an increased awareness of the line between science having established rules and science as complex (Table 4.20). Table 4.21 contains the items from Factor 5 which all have to do with solving science problems.

Factor 4: Awareness of Complexity in Science
3.Obviously, computer simulations can predict the behavior of physical objects like comets. But simulations can also help scientists estimate things involving the behavior of *people*, such as how many people will buy new television sets next year. 10. Often, a scientific principle or theory just doesn't make sense. In those cases, you have to accept it and move on, because not everything in science is supposed to make sense. 17. To understand chemistry and physics, the formulas (equations) are really the main thing; the other material is mostly to help you decide which equations to use in which situations.

Table 4-20: Items for Factor 4 of Model (MAY)

Factor 5: Problem-solving in Science
4. When it comes to science, most students either learn things quickly, or not at all. 13. If physics and chemistry teachers gave *really clear* lectures, with plenty of real-life examples and sample problems, then most good students could learn those subjects without doing lots of sample questions and practice problems on their own. 15. When solving problems, the key thing is knowing the methods for addressing each particular type of question. Understanding the "big ideas" might be helpful for specially-written problems, but not for most regular problems. 18. If someone is trying to learn physics, is the following a good kind of question to think about? Two students want to break a rope. Is it better for them to (1) grab opposite ends of the rope and pull (like in tug-of-war), or (2) tie one end of the rope to a wall and both pull on the other end together?

Table 4-21: Items for Factor 5 of Model (MAY)

4.3.5.1 Reliability of Factor Structure of Model$_{May}$

Table 4-22 provides the Cronbach alpha scores for each factor for Model$_{MAY}$. Factors 1, 2, 3 and 4 have Cronbach alpha scores above the acceptable limit of 0.5 (Peterson, 1994). However, Factor 5 of Model$_{MAY}$ has a Cronbach alpha score of 0.476. We still retain this factor because problem solving in science is an emergent theme from the qualitative data (Chapter 5) (Nashon & Madera, 2013).

Factor	Name Given to Factor	Number of Items	Cronbach Alpha
1	Multiple perspectives about success in science	7	0.567
2	Doing well in science	10	0.530
3	Awareness of the Structure of Scientific Knowledge (pieces vs whole)	6	0.505
4	Awareness of the complexity in science	3	0.554
5	Problem-solving in science	4	0.476

Table 4-22: Cronbach Alpha Scores for Factors of Model (MAY)

4.3.5.2 Confirmatory Factor Analysis of Model$_{MAY}$

Model$_{May}$ is not a permissible fit for the Round$_{JULY}$ as indicated by CMIN/df and $p <$ 0.05 and a low CFI value (Table 4.23). Moreover, the iteration limit was reached when running CFA for Model$_{MAY}$ on Round$_{JULY}$ so any further analysis of persistent factors using CFA would be erroneous.

	Goodness of Fit (CMIN/df, *p*-value, CFI)
Round$_{SEPT}$	N/A
Round$_{MAY}$	N/A
Round$_{JULY}$	1.903, $p < 0.05$ CFI = 0.164

Table 4-23: Goodness of Fit of Model(MAY) on Round(JULY)

4.3.6 Factor Structure of Model$_{JULY}$

The Scree plot (Figure 4.11) suggests 4, 5 or 6 factors before an inflection point. Applying the other statistical criteria leaves us with 4 or 5 factors. I analyzed the data with both 4 and 5 factors and 4 factors made more “conceptual” sense. These four factors account for 40.3% of the variance (Figure 4.12).

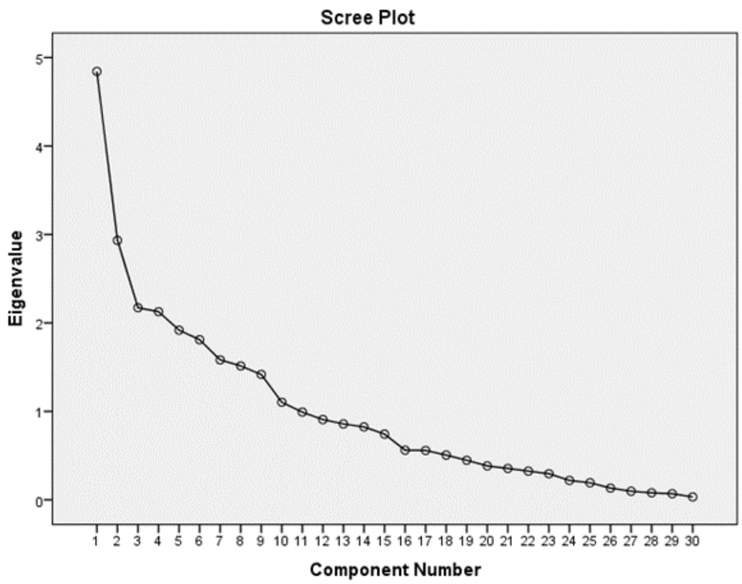

Figure 4-11: Scree Plot for Model (JULY)

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.843	16.143	16.143	4.843	16.143	16.143	4.445	14.815	14.815
2	2.933	9.776	25.919	2.933	9.776	25.919	2.933	9.776	24.591
3	2.171	7.238	33.157	2.171	7.238	33.157	2.484	8.281	32.872
4	2.127	7.090	40.247	2.127	7.090	40.247	2.213	7.376	40.247
5	1.919	6.395	46.642						
6	1.810	6.033	52.676						
7	1.582	5.274	57.950						
8	1.513	5.045	62.995						
9	1.418	4.725	67.720						
10	1.103	3.678	71.398						
11	.992	3.306	74.704						
12	.908	3.026	77.730						
13	.858	2.859	80.589						
14	.824	2.747	83.336						
15	.743	2.478	85.814						
16	.562	1.872	87.686						
17	.558	1.861	89.547						
18	.506	1.685	91.232						
19	.447	1.491	92.724						
20	.384	1.279	94.002						
21	.355	1.183	95.185						
22	.325	1.083	96.268						
23	.295	.983	97.251						
24	.219	.731	97.982						
25	.193	.644	98.627						
26	.133	.442	99.068						
27	.097	.325	99.393						
28	.079	.265	99.658						
29	.069	.232	99.890						
30	.033	.110	100.000						

Figure 4-12: % Variance for Model(JULY)

The items and their loadings are given in Figure 4.13:

	Component			
	1	2	3	4
JulyQ1	.614	.195	.185	.030
JulyQ15	.608	.000	.210	-.043
JulyQ19	.607	-.009	.165	-.525
JulyQ17	.603	.023	-.003	.166
JulyQ20	.579	.026	.001	-.080
JulyQ10	.556	.092	-.128	.214
JulyQ14	.536	.149	.162	.080
JulyQ12	.501	-.133	.159	-.097
JulyQ5	.396	.217	.291	.175
JulyQ2	-.359	.120	-.117	.069
JulyQ26	.417	.171	-.603	-.141
JulyQ30	.317	.041	.098	-.562
JulyQ24	.077	.701	-.173	-.074
JulyQ16	.175	.683	.094	-.079
JulyQ9	.285	.668	.009	.117
JulyQ22	-.380	.518	.154	-.023
JulyQ21	-.386	.488	.389	.348
JulyQ29	-.118	.399	-.146	-.044
JulyQ27	.250	.397	-.065	-.071
JulyQ25	.020	.203	-.154	-.399
JulyQ23	.009	-.287	.077	-.309
JulyQ3	.162	.019	.570	.111
JulyQ8	.389	.003	.516	-.168
JulyQ6	.174	-.281	.510	-.156
JulyQ7	.401	.070	.452	.079
JulyQ11	.186	-.303	.446	-.048
JulyQ13	.068	-.276	-.489	.583
JulyQ4	.273	.246	.272	.513
JulyQ18	.407	.177	.059	.481
JulyQ28	.295	-.241	.018	.389

Figure 4-13: Item Loadings for Model(JULY)

The items loaded onto each of the four factors are provided in the tables, along with the conceptual meanings of the items grouped into the same factor. When appropriate, items with largest loading items are highlighted in bold.

The items in Factor 1 of $Model_{JULY}$ (Table 4.24) overlap with the items in Factor 2 of $Model_{MAY}$, thus this factor is given the same title, “Doing well in Science”. Similarly, the items of factor 2 of $Model_{JULY}$ (Table 4.25) overlap with the items of Factor 1 of $Model_{SEPT}$ and so is given the same title, “Success in Science as a function of hard work or innate ability”.

Factor 1: Doing Well in Science
1. **Tamara just read something in her science textbook that seems to disagree with her own experiences. But to learn science well, Tamara shouldn’t think about her own experiences; she should just focus on what the book says.**
2. When it comes to understanding physics or chemistry, remembering facts isn’t very important.
5. If someone is having trouble in physics or chemistry class, studying in a better way can make a big difference.
10. Often, a scientific principle or theory just doesn’t make sense. In those cases, you have to accept it and move on, because not everything in science is supposed to make sense.
12. When learning science, people can understand the material better if they relate it to their own ideas.
14. Understanding science is really important for people who design rockets, but not important for politicians.
15. **When solving problems, the key thing is knowing the methods for addressing each particular type of question. Understanding the “big ideas” might be helpful for specially-written problems, but not for most regular problems.**
17. To understand chemistry and physics, the formulas (equations) are really the main thing; the other material is mostly to help you decide which equations to use in which situations.
19. **Scientists are having trouble predicting and explaining the behavior of thunder storms. This could be because thunder storms behave according to a very complicated or hard-to-apply set of rules. Or, that could be because some thunder storms don’t behave consistently according to *any* set of rules, no matter how complicated and complete that set of rules is. In general, why do scientists sometimes have trouble explaining things? Please read all options before choosing one.**
20. In chemistry, how do the most important formulas relate to the most important concepts? Please read all choices before picking one.
26. Justin: When I’m learning science concepts for a test, I like to put things in my own words, so that they make sense to me. Dave: But putting things in your own words doesn't help you learn. The textbook was written by people who know science really well. You should learn things the way the textbook presents them.
30. Jessica and Mia are working on a chemistry homework assignment together... Jessica: O.K., we just got problem #1. I think we should go on to problem #2. Mia: No, wait. I think we should try to figure out why the thing takes so long to reach the ground. Jessica: Mia, we know it’s the right answer from the back of the book, so what are you worried about? If we didn’t understand it, we wouldn’t have gotten the right answer. Mia: No, I think it’s possible to get the right answer without really understanding what it means.

Table 4-24: Factor 1 of Model (JULY). Items in Bold Have the Largest Factor Loadings.

Factor 2: Success in science using hard work or natural ability
9. Someone who doesn't have high natural ability can still learn the material well even in a hard chemistry or physics class. **16. Given enough time, almost everybody could learn to think more scientifically, if they really wanted to.** **21.** To be successful at *most things in life*... **22.** To be successful at *science*... **23.** Of the following test formats, which is best for measuring how well students understand the material in chemistry? Please read each choice before picking one. **24.** **Brandon: A good science textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each topic as a separate "unit," because they're not really separate.** **Jamal: But most of the time, each chapter is about a different topic, and those different topics don't always have much to do with each other. The textbook should keep everything separate, instead of blending it all together. With whom do you agree? Read all the choices before circling one.** **25.** **Anna**: I just read about Kay Kinoshita, the physicist. She sounds naturally brilliant. **Emily**: Maybe she is. But when it comes to being good at science, hard work is more important than "natural ability." I bet Dr. Kinoshita does well because she has worked really hard. **Anna**: Well, maybe she did. But let's face it, some people are just smarter at science than other people. Without natural ability, hard work won't get you anywhere in science! **27.** **Julia:** I like the way science explains how things I see in the real world. **Carla:** I know that's what we're "supposed" to think, and it's true for many things. But let's face it, the science that explains things we do in lab at school can't really explain earthquakes, for instance. Scientific laws work well in some situations but not in most situations. **Julia:** I still think science applies to almost all real-world experiences. If we can't figure out how, it's because the stuff is very complicated, or because we don't know enough science yet. **29.** **Jose:** In my opinion, science is a little like fashion; something that's "in" one year can be "out" the next. Scientists regularly change their theories back and forth. **Miguel:** I have a different opinion. Once experiments have been done and a theory has been made to explain those experiments, the matter is pretty much settled. There's little room for argument.

Table 4-25: Factor 2 of Model (JULY). Items in Bold Have the Largest Factor Loadings.

For Factor 3, the items are related to an awareness of the self in science (Table 4.26). For example, a teacher teaching or a student taking a test have an awareness of their own understanding or performance in science. Both the item on simulations and the item on controversial topics refer to modelling in science. Modelling requires a scientist to interpret and these interpretations are based on their own perspectives influenced by the paradigm at the time (Kuhn, 1962).

Factor 3: Awareness of Self in Science
3.Obviously, computer simulations can predict the behavior of physical objects like comets. But simulations can also help scientists estimate things involving the behavior of *people*, such as how many people will buy new television sets next year. 6. When it comes to controversial topics such as which foods cause cancer, there's no way for scientists to evaluate which scientific studies are the best. Everything's up in the air! 7. A teacher once said, "I don't *really* understand something until I teach it." But actually, teaching doesn't help a teacher understand the material better; it just reminds her of how much he or she already knows. 8. Scientists should spend almost all their time gathering information. Worrying about theories can't really help us understand anything. 11. When handing in a physics or chemistry test, you can generally have a sense of well you did even before talking about it with other students.

Table 4-26: Factor 3 of Model (JULY)

Items in Factor 4 (Table 4.27) overlap with items in Factor 5 of Model$_{SEPT}$ (labelled as Learning Science in the Classroom) but includes a broader context, not just in the classroom. I labelled this factor as "Learning about science" following Hodson, (2014) as his definition, "Learning about Science" is described as developing an understanding of scientific inquiry, role of science in society, and how scientific knowledge is created. This factor indicates students begin to relate what they experience in the classroom to real-life, which is an aspect of sophisticated epistemology (White et al., 1999).

Factor 4: Learning about Science
4. When it comes to science, most students either learn things quickly, or not at all. 13. If physics and chemistry teachers gave *really clear* lectures, with plenty of real-life examples and sample problems, then most good students could learn those subjects without doing lots of sample questions and practice problems on their own. 18. If someone is trying to learn physics, is the following a good kind of question to think about? Two students want to break a rope. Is it better for them to (1) grab opposite ends of the rope and pull (like in tug-of-war), or (2) tie one end of the rope to a wall and both pull on the other end together? 25. Anna: I just read about Kay Kinoshita, the physicist. She sounds naturally brilliant. Emily: Maybe she is. But when it comes to being good at science, hard work is more important than "natural ability." I bet Dr. Kinoshita does well because she has worked really hard. Anna: Well, maybe she did. But let's face it, some people are just smarter at science than other people. Without natural ability, hard work won't get you anywhere in science! 28. Leticia: Some scientists think the dinosaurs died out because of volcanic eruptions, and others think they died out because an asteroid hit the Earth. Why can't the scientists agree? Nisha: Maybe the evidence supports both theories. There's often more than one way to interpret the facts. So we have to figure out what the facts mean. Leticia: I'm not so sure. In stuff like personal relationships or poetry, things can be ambiguous. But in science, the facts should speak for themselves.

Table 4-27: Factor 4 of Model (JULY)

4.3.6.1 Reliability of Factor Structure of Model$_{July}$

Table 4-28 provides the Cronbach alpha scores for each factor for Model$_{JULY}$. Factors 1, 2, and 3 have Cronbach alpha scores that are above the acceptable limit of 0.5 (Peterson, 1994). However, factor 4 of Model$_{JULY}$ has a Cronbach alpha score of 0.476. We still retain this factor because of the strong theoretical validity (Nashon & Madera, 2013), as discussed in the previous section (4.3.2.5).

Factor	Name Given to Factor	Number of Items	Cronbach Alpha
1	Doing well in science	12	0.703
2	Success in science using hard work or natural ability	9	0.553
3	Awareness of self in science	5	0.601
4	Learning about science	5	0.481

Table 4-28: Cronbach Alpha Scores for Factors of Model (JULY)

4.3.7 Key Finding 3: EFA Leads to Three Models and CFA Indicates that Model$_{SEPT}$ is the Better Fit.

Exploratory factor analysis of Round$_{SEPT}$, Round$_{MAY}$ and Round$_{JULY}$ led to three different models of the underlying factor structure for each round. This suggests a change in student dominant epistemological components occurred.

Exploratory and confirmatory factor analyses indicate that of all the models, Model$_{SEPT}$ is a better fit for all three rounds. Table 4-29 summarizes the goodness of fit of each model on the different rounds. Although Model$_{EBAPS}$ and Model$_{SEPT}$ have similar overall results, the error estimates for the dimensions in each model (Figures 4-2, 4-6 and 4-7) show that more of the factors from Model$_{SEPT}$ persisted compared to Model$_{EBAPS}$. The factors from Model$_{SEPT}$ emerged at the start of the program before the intervention of the Vantage program came into full effect. Some of the factors from Model$_{SEPT}$ may have become validated during the program.

	Goodness of Fit (CMIN/df, *p*-value, CFI)			
	Model$_{EBAPS}$	Model$_{SEPT}$	Model$_{MAY}$	Model$_{JULY}$
Round$_{SEPT}$	1.389, $p < 0.05$ CFI = 0.268	N/A	N/A	N/A
Round$_{MAY}$	1.463, $p <0.05$ CFI = 0.409	1.463, $p < 0.05$ CFI = 0.395	N/A	N/A
Round$_{JULY}$	1.616, $p <0.05$ CFI = 0.392	1.755, $p < 0.05$ CFI = 0.320	1.903, $p <0.05$ CFI = 0.164 *Iteration limit reached	N/A

Table 4-29: Goodness of Fit of Four Models

The focus of the following sections will be on Model$_{SEPT}$ and how Model$_{SEPT}$ evolved over time.

4.3.8 Transformation of Model$_{SEPT}$

To examine the transformation of the factors from Model$_{SEPT}$, I used results from Model$_{MAY}$ and Model$_{JULY}$ descriptive analyses, CFA and from repeated measures ANOVA.

Table 4.30 summarizes the average scores of each factor from Model$_{SEPT}$ for all students who completed each round. Results indicate that there is no significant difference between the average scores in Round$_{MAY}$ and Round$_{JULY}$. The average overall epistemology scores did change between Round$_{SEPT}$ and Round$_{MAY/JULY}$. As well, the average scores in the factors, “Authorities of science knowledge” and “Confidence in understanding Science” changed between $\text{Round}_{\text{SEPT}}$ and $\text{Round}_{\text{MAY/JULY}}$. The average scores of the other factors do not significantly change over the three rounds. This suggests that with the 11-month programs, students held different epistemological views overall and, in particular, with views on "Authorities of science knowledge" and "Confidence in understanding science" compared to September 2015.

	Average Score ± Standard deviation					
Round	$\text{EBAPS}_{\text{Overall}}$	$\text{Model}_{\text{SEPT}}$ Success in Sci using hard work	$\text{Model}_{\text{SEPT}}$ Authorities in Sci Knowledge	$\text{Model}_{\text{SEPT}}$ Confidence in understanding Sci	$\text{Model}_{\text{SEPT}}$ Absolutism in Sci	$\text{Model}_{\text{SEPT}}$ Learning Sci
$\text{Round}_{\text{SEPT}}$ $N = 75$	3.41 ± 0.29	3.20 ± 0.63	3.59 ± 0.54	3.80 ± 0.70	3.43 ± 0.52	2.99 ± 0.64
$\text{Round}_{\text{MAY}}$ $N = 66$	3.28 ± 0.29	3.19 ± 0.57	3.36 ± 0.54	3.40 ± 0.58	3.40 ± 0.58	2.98 ± 0.62
$\text{Round}_{\text{JULY}}$ $N = 53$	3.29 ± 0.34	3.21 ± 0.57	3.34 ± 0.57	3.46 ± 0.67	3.40 ± 0.50	3.03 ± 0.56

Table 4-30: Average Factor Scores Over Time for Model (SEPT)

To ensure triangulation, a one-way Repeated Measures ANOVA was also used to examine the evolution of underlying epistemological construct over time. I did not expect the results to be the same as descriptive analysis or CFA since both tools are using different methods. The repeated measures ANOVA looks at average scores only from students who completed the survey in the three rounds. Each student's average score of the items in each factor from $\text{Model}_{\text{SEPT}}$ was compared over the three rounds to assess which factors persisted over the other two rounds. Forty eight students (*N* = 48) completed the survey for all three rounds. A one-way repeated measures ANOVA was run for each factor found in Round 1 using a Bonferroni post-hoc test.

The scores from Factors 1, 2, 4 and 5 in $Model_{SEPT}$ are all consistent in the three rounds of data collection. Factor 3 ("confidence in understanding science") was statistically significantly different between $Round_{SEPT}$ and $Round_{MAY}$ and between $Round_{SEPT}$ and $Round_{JULY}$ but there was no statistically significant difference between $Round_{MAY}$ and $Round_{JULY}$. Below are the details.

$Model_{SEPT}$ Factor 1: Success in science using hard work or natural ability

Mauchly's test of sphericity indicated that the assumption of sphericity has not been violated, $\chi^2(2) = 3.40$, $p = 0.183$. The one-way repeated measures ANOVA indicated that the means for Factor 1 did not lead to any statistically significant changes in Scores over time, $F(2,94) = 0.057$, $p = 0.945$ (Table 4.31).

Descriptive Statistics

	Mean	Std. Deviation	N
Sept_Factor1	3.1925	.61197	48
May_Factor1	3.1833	.55128	48
July_Factor1	3.1607	.56272	48

Table 4-31: Descriptive Statistics over Time for Factor 1 of Model (SEPT)

Model$_{SEPT}$ Factor 2: Authorities of Science Knowledge

Mauchly's test of sphericity indicated that the assumption of sphericity has not been violated, $\chi^2(2) = 5.57$, $p = 0.062$. The one-way repeated measures ANOVA indicate that the means for Factor 2 did not lead to statistically significant change in scores over time, $F\,(2,96) = 2.484$, $p = 0.089$.

Descriptive Statistics

	Mean	Std. Deviation	N
Factor2_Sept	3.5491	.75308	48
Factor2_May	3.3803	.54116	48
Factor2_July	3.3325	.58589	48

Table 4-32: Descriptive Statistics Over Time for Factor 2 of Model (SEPT)

Model$_{SEPT}$ Factor 3: Confidence in Understanding Science

Mauchly's test of sphericity indicated that the assumption of sphericity has not been violated, $\chi^2(2) = 3.78$, $p = 1.51$. The one-way repeated measures ANOVA indicate that the means for Factor 2 DID lead to a statistically significant changes in scores over time, $F\,(2,96) = 7.02$, $p = 0.001$ with partial $\eta^2 = 0.130$.

Descriptive Statistics

	Mean	Std. Deviation	N
Factor3_Sept	3.8368	.72076	48
Factor3_May	3.4340	.60312	48
Factor3_July	3.4792	.68729	48

Table 4-33: Descriptive Statistics Over Time for Factor 3 of Model (SEPT)

Post-hoc analysis with a Bonferroni adjustment revealed that Factor 3 means statistically significantly decreased from September 2015 to May 2015 (0.403, $p < 0.05$) and from September to July (0.358, $p < 0.05$) but not from May to July (0.045, $p = 1$).

Model$_{SEPT}$ Factor 4: Absolutism in Science

Mauchly's test of sphericity indicated that the assumption of sphericity has not been violated, $\chi^2(2) = 1.19$, $p = 0.551$. The one-way repeated measures ANOVA indicated that the means for Factor 4 did not lead to any statistically significant changes in Scores over time, $F(2,94) = 0.256$, $p = 0.775$.

Descriptive Statistics

	Mean	Std. Deviation	N
Factor4_Sep	3.4722	.54054	48
Factor4_May	3.4417	.37863	48
Factor4_July	3.4107	.49891	48

Table 4-34: Descriptive Statistics Over Time for Factor 4 of Model (SEPT)

Model$_{SEPT}$ Factor 5: Learning Science in the Classroom

Mauchly's test of sphericity indicated that the assumption of sphericity has not been violated, $\chi^2(2) = 3.447$, $p = 0.178$. The one-way repeated measures ANOVA indicated that the means for Factor 4 did not lead to any statistically significant changes in scores over time, F (2,94) = 0.379, $p = 0.685$.

Descriptive Statistics

	Mean	Std. Deviation	N
Factor5_Sep	2.9844	.67321	48
Factor5_May	3.0677	.62684	48
Factor5_July	3.0677	.57598	48

Table 4-35: Descriptive Statistics Over Time for Factor 5 of Model (SEPT)

Figure 4-6 provides the unstandardized regression estimates of items from CFA using $Model_{SEPT}$ on $Round_{MAY}$ responses. The standard errors are consistently high for items in the factor, "Absolutism in Science" which suggests that this factor was not dominant in $Round_{MAY}$. The other factors have one or two items with higher standard errors suggesting that those items should be removed but the factor is still persistent.

Figure 4-7 provides the unstandardized regression estimates of items using $Model_{SEPT}$ on $Round_{JULY}$ responses. Although the standard errors are higher for items in the factor, "Success in Science using hard work or natural talent", they are not significantly higher than the others. The other factors have one or two items with abnormal standard errors which suggests that those items should be removed but the factor is still persistent. The factor "absolutism", which was not dominant in $Round_{MAY}$ is again dominant in $Round_{JULY}$.

4.3.9 Implications of Descriptive Statistics, CFA, and One-way Repeated Measures ANOVA as Measures of Evolution of Underlying Factor Structure of $Model_{SEPT}$ over Time

Descriptive analysis of $Model_{SEPT}$, CFA and one-way repeated measures ANOVA indicate that there were changes to epistemologies over time and are summarized in Table 4-36.

	Descriptive Analysis	One-way Repeated Measures ANOVA	Confirmatory Factor Analysis: Error Estimates
Significant changes in Scores for:	• Overall Epistemology between $Round_{SEPT}$ and $Round_{MAY}$/$Round_{JULY}$ • Confidence in Understanding Science Factor between $Round_{SEPT}$ and $Round_{MAY}$/$Round_{JULY}$ • Authorities in Science between $Round_{SEPT}$ and $Round_{MAY}$/$Round_{JULY}$	• Overall Epistemology between $Round_{SEPT}$ and $Round_{MAY}$/$Round_{JULY}$ • Confidence in Understanding Science Factor between $Round_{SEPT}$ and $Round_{MAY}$/$Round_{JULY}$	• Absolutism in Science between $Round_{SEPT}$ and $Round_{MAY}$

Table 4-36: Summary of Significant Changes in Model(SEPT) as Measured by Descriptive Statistics, One-way Repeated Measures ANOVA and CFA

Descriptive analysis and one-way Repeated measures ANOVA suggest that students' epistemologies changed over time. In particular, descriptive analysis indicates that students held different views in their overall epistemology and on "Authorities of Science Knowledge" and "Confidence in Understanding Science" as compared to the start of the program in September 2015. One-way repeated measures ANOVA suggests that students held statistically significant different views in the factor, "Confidence in Understanding Science" after eight months of the program as compared to the start of the program. Examining the standard errors of regression weight estimates in CFA of $Model_{SEPT}$ applied to $Round_{MAY}$ and $Round_{JULY}$ indicates that factor "Absolutism in science" was not a dominant epistemology factor over time.

4.4 Analysis III: Correlation Analysis

To examine whether there is a relationship between the epistemologies of students entering first-year university and their experiences of pedagogy in CHEM 121 and CHEM 123, SPSS version 24 was used to calculate a Pearson coefficient between various CHEM 121 and CHEM 123 classroom assessment grades (such as final exam scores, homework scores, laboratory scores, etc) with $Round_{SEPT}$ scores. Student performance is only one aspect of the student experience in first year. Other aspects are discussed throughout the thesis, including in the qualitative analysis. Schrommer (1993) ran a similar analysis when she looked at the relationship between epistemology scores and high school GPA using correlation coefficient. $Round_{SEPT}$ is the focus of the analysis since we are concerned with student epistemologies as they enter the program. Only the factor structure of $Model_{SEPT}$ is tested, in addition to overall mean EBAPS score since CFA found $Model_{SEPT}$ to be the better fit of all models.

After checking the assumptions identified in section 3.8 for correlation analysis, a significant correlation was assessed based on the size of the Pearson Correlation Coefficient, the significance (*p*-value) and the regression plots. Cohen, (1988) states that correlations between 0.1 and 0.3 are small, 0.3 and 0.5 are medium and above 0.5 are large. Hemphill, (2003) conducted a review of several large studies and suggests a guideline of anything below 0.2 as small, correlations between 0.2 and 0.3 as medium and above 0.3 as large. During analysis, $p < 0.1$ was used to identify relationships for which a regression plot was drawn. Regression plots were used to visually determine if a linear relationship is only due to outliers (Appendix B). Relationships that met the criteria were highlighted in the results section below.

4.4.1 Correlation Analysis between CHEM 121 Assessment Scores and $Round_{SEPT}$

The factor, “Confidence in understanding science” is the factor that is most correlated with CHEM 121 activities (Table 4.37) and the correlations are “moderate” (Hemphill, 2003). In fact, the total CHEM 121 grade is correlated with this factor. Activities such as homework and laboratory experienced the strongest correlations with epistemological constructs. The laboratory uses inquiry-based learning as the teaching pedagogy. This is consistent with the findings from Schommer, (1993b) who found that epistemological beliefs were correlated with high school GPA and each epistemological belief relates to different aspects of academic performance.

			Model$_{SEPT}$ Factor				
Activity	Stats (N = 75)	Overall EBAPS Score	Hardwork vs Innate Ability	Authority	Confidence	Absolutism	Learning
Midterm 1	Pearson Coefficient				**0.217**		
	Significance (2 tailed)				**0.061**		
Midterm 2	Pearson Coefficient						
	Significance (2 tailed)						
Test 1	Pearson Coefficient						**0.234**
	Significance (2 tailed)						**0.043**
Test 2	Pearson Coefficient				**.248**		
	Significance (2 tailed)				**.032**		
Homework	Pearson Coefficient	**.227**			**.431**		**.237**
	Significance (2 tailed)	**.050**			**.000**		**.040**
In-class participation (clickers)	Pearson Coefficient	.249			.319		.254
	Significance (2 tailed)	.031			.005		.028
Online quizzes	Pearson Coefficient				.262		
	Significance (2 tailed)				.023		
Final exam	Pearson Coefficient				.227		
	Significance (2 tailed)				.050		
Lab	Pearson Coefficient	**.260**			**.312**	**.230**	**.198**
	Significance (2 tailed)	**.024**			**.006**	**.047**	**.088**
Total Grade	Pearson Coefficient				.229		
	Significance (2 tailed)				.048		

Table 4-37: Correlation Analysis Results for CHEM 121

**graphs indicate that regressions involving clickers grades and online quizzes have too many outliers and should not be considered.
**Bold indicates a statistically significant result based on the size of the Pearson Coefficient, the *p*-value and the regression graph.

4.4.2 Correlation Analysis between CHEM 123 Assessment Scores and $Round_{SEPT}$

The factor, "Confidence in understanding science" is the factor that is most correlated with CHEM 123 activities and the correlations are "moderate" (Table 4.38). In fact, the total CHEM 123 score is correlated with this factor. A laboratory report experienced the strongest correlations with epistemological constructs. This particular laboratory report gave students more opportunities to engage with elements of scientific inquiry, such as reading primary literature and choosing their own research question.

			ModelSEPT Factor				
Activity	Stats (N = 60)	Overall EBAPS Score	Hardwork vs Innate Ability	Authority	Confidence	Absolutism	Learning
Midterm	Pearson Coefficient	**.210**			**.332**		
	Significance (2 tailed)	**.108**			**.009**		
Quizzes	Pearson Coefficient				.303		
	Significance (2 tailed)				.019		
Homework	Pearson Coefficient				**.261**		
	Significance (2 tailed)				**.044**		
Tutorial	Pearson Coefficient						
	Significance (2 tailed)						
Clicker	Pearson Coefficient						
	Significance (2 tailed)						
A Laboratory Report (Exp't 9)	Pearson Coefficient	.324			.391		.275
	Significance (2 tailed)	.012			.002		.034
Final Exam	Pearson Coefficient				**.240**		
	Significance (2 tailed)				**.064**		
Lab	Pearson Coefficient				**.240**		
	Significance (2 tailed)				**.064**		
Total Grade	Pearson Coefficient				**.276**		
	Significance (2 tailed)				**.033**		

Table 4-38: Correlation Analysis Results for CHEM 123

**graphs indicate to remove online quizzes and clickers grades with the "Confidence" factor.
**remove clicker with learning.
**Bold indicates a statistically significant result based on the size of the Pearson Coefficient, the *p*-value and the regression graph.

4.5 Summary of Key Findings

As a result of quantitative analysis of the questionnaire data, the key findings related to the research questions are as follows:

- The overall mean scores for the questionnaire indicate a statistically significant change ($p < 0.01$) from $Round_{SEPT}$ and $Round_{JULY}$.
- One-way repeated measures ANOVA indicates that the overall mean scores are significantly different between $Round_{SEPT}$ and $Round_{JULY}$ ($p = 0.05$). This score implies student experienced some change in epistemologies over time.
- Confirmatory factor analysis indicates that $Model_{EBAPS}$ was not statistically significant for describing the factor structure of any of the three rounds.
- Exploratory factor analysis of each round yielded three different dominant factor structures. This points towards a change in epistemologies.
- Confirmatory factor analysis indicated that $Model_{SEPT}$ is the better fit for three rounds compared to the other models.
- Descriptive analysis of $Model_{SEPT}$, CFA and one-way repeated measures ANOVA indicate that there was a transformation of $Model_{SEPT}$ over time. In particular, descriptive analysis points to a high probability that students held different views in their overall epistemologies and views on "Authorities of Science Knowledge" and "Confidence in Understanding Science" as compared to the start of the program in September 2015. One-way repeated measures ANOVA suggests that students held statistically significant different views in the factor, "Confidence in Understanding Science" after 8 months of the program as compared to the start of the program. Examining the standard errors of regression weight estimates in CFA of $Model_{SEPT}$ applied to $Round_{MAY}$ indicates that

factor "Absolutism in science" was not a dominant epistemology factor in $Round_{MAY}$. This indicates that some epistemological factors that were dominant in $Round_{SEPT}$ were no longer dominant over time.

- The factor, "Confidence in understanding science" from $Model_{SEPT}$ is the factor that is most correlated with both CHEM 121 and CHEM 123 grades and the correlations are "moderate". Laboratory activities in both CHEM 121 and CHEM 123 experienced correlations with the most epistemological constructs.

The key findings from the quantitative analysis indicate that at the start of the program in September 2015, students viewed science as a classroom endeavour, as right/wrong and considering scientific knowledge to reside with an external authority. As the program progressed, students' dominant epistemologies still included views of science as a classroom endeavor as factors related to this topic emerged in both May and July 2016. At the same time, students became more aware of the development and structure of science knowledge, which emerged as a dominant aspect of epistemology in May 2016. In July 2016, "Awareness of self in science" emerged as a dominant aspect of epistemology, indicating that student views were moving towards considering themselves and their peers as sources of scientific knowledge. The quantitative data also suggest that some aspects of students' epistemologies changed over time while others did not change. Student epistemologies were related to academic grades, particularly for the laboratory.

Chapter 5: Qualitative Data Analysis and Results

This chapter begins with a discussion of how the interview data were analyzed. The bulk of this chapter is devoted to the exploration of how the data answered the research questions.

5.1 Qualitative Data Analysis

The interview data were elicited through six focus group interviews (four held in January 2016 and two held in May 2016), two one-on-one, semi-structured, 40-minute interviews and two 20-minute one-on-one task-based interviews that followed a think aloud protocol were held at the end of the semi-structured interviews consistent with guidance from Lising and Elby (2005). The focus group interviews were held at the end of Term 1 (end of CHEM 121) and at the start of Term 3 (start of CHEM 123) to coincide with the students' chemistry course schedule. The one-on-one semi-structured and task-based interviews were held at the end of May 2016 and in July 2016, which corresponded to $Round_{MAY}$ and $Round_{JULY}$ of the EBAPS survey. This allowed for the opportunity to include follow-up questions to deepen understanding of survey responses (interviews were avoided for $Round_{SEPT}$ because the researcher was also teaching the participants at that time).

Data analysis occurred in three steps. The initial step of analysis involved preliminary data analysis where every time data were collected (every interview), I reflected and documented all data relevant to the research questions, emerging themes, and areas that required follow-up (Grbich, 2007). My analysis was guided by broader descriptions of epistemology informed by the literature (Baxter Magolda, 1992; Hofer & Pintrich, 1997; Louca et al., 2004; Schommer, 1990). I compared participants' responses among one another and within each participant;

looking for not only similarities but also differences between and among them (Ornek, 2008). Classroom observations and my own reflections on teaching CHEM 121, as well as, observations of CHEM 123 lecture and laboratory were used to document student actions in response to the different pedagogies, to supplement interview data and to identify areas that required follow-up. During the preliminary process, I identified emergent patterns.

A transcript including descriptive details (Grbich, 2007) was generated for each interview data set. After the interviews were completed and transcribed, I categorized the data using thematic analysis (Merriam, 1998; Miles & Huberman, 1994) to address the study objectives (Miles & Huberman, 1994; Yin, 2014). Thematic analysis is a search for themes that are identified through careful reading and re-reading of data as being important to the description of the phenomenon that is being studied (Fereday & Muir-Cochrane, 2006). I referred to my preliminary notes as I came up with the themes. At this stage, I also focused on each student as a "case"- looking at all the data from one student as a whole (Yin, 2014). I followed Aronson's (1995) approach to thematic analysis. First, the researcher looks for patterns of experiences in the data and then identifies all the relevant data that fits into each pattern. The next step is to combine and catalogue related patterns into themes. Themes consist of components and ideas that fit together in a meaningful way. Finally, the last step is to draw upon the literature to support the arguments for the themes (Aronson, 1995). Transcripts of each interview data set were sifted through to identify, describe, and interpret themes related to the students' epistemologies as well as any changes in their epistemologies.

The emergent themes, which are supported by select verbatim quotes and excerpts from the interview transcripts, represent the voices of participants who are identified by pseudonyms. The four key themes are:

1. Changes in epistemologies in post-experience conversations
2. Hard work/innate ability as the hallmark of success
3. Peer and self-learning are considered complementarity sources of knowledge
4. Success in problem solving depended on student modes of learning

Consistent with concurrent triangulation approach, the final step of analysis involves comparing the themes from the quantitative and qualitative data and looking for collaborations to form new variables (Cresswell et al., 2003). This exploration will be fully discussed in Chapter 6. The three steps used in this study for data analysis, which is consistent with Concurrent Triangulation design were: (1) Qualify quantitative data: Using factor analysis to examine the survey data. These factors then become themes; (2) Use thematic analysis to analyze qualitative data and (3). Compare the results from the quantitative and qualitative data and look for collaborations to form new variables (Cresswell et al., 2003). I will now present and discuss each of the four themes that emerged from the qualitative analysis.

5.2 Results and Interpretation

5.2.1 Theme 1: Changes in Epistemologies in Post-Experience Conversations

The students understanding of science has changed from high school through an increased awareness that science is complicated. According to the participants, high school science was more about memorizing and following the rules. Roya said, “In high school, I thought it was easy to get a good score because you just have to remember things.” Adam claimed, “In high school, you know the rules” and Kevin went on with, “In my high school, my teachers teach a concept and just tell us to memorize that.” Kay added, “In high school I learned enthalpy but I only learned how to calculate it.”

The students’ experiences in university changed their understanding of science. Adam shared, “I see university as deeper learning. Now we don’t just learn rules but why or how the rules came about. This allows for more connections.” Others said that they know science should be connected but they have trouble seeing those connections, sometimes: “We need to understand science, not just memorize it.” and Roya echoed, “In university, you can’t just remember, you have to think deeper to get good marks.” As they learned more science in university, students found it increasingly difficult to describe or define science compared to high school. In high school, science felt more “simple.” Roya finished with, “Now, I say science is terrible! It is much more complicated that I thought!”

Many students described science as more complicated because they are being exposed to how the science is developed. Students also articulated that they did not have much opportunity to consider how science knowledge is developed before coming to UBC. Along these lines, Dante said, “[the Vantage Math Instructor] tried to teach us derivative and how it comes from the Limit but in high school, we only learn derivative.” Fancy added:

> In China, my teacher tells us the content of science. I don’t know how the scientists get it. At UBC, the instructors always give us time to come up with how we can fix the problem

> ourselves. So if we want to develop something or use our own logic, then it is very important to know the process of how scientists get knowledge.

From their coursework at UBC, students were able to give specific details of what is involved in the development of scientific knowledge. For example, Bowen asserted:

> You have to make assumption at the start and that time imagination can be really important. For example, I read [in CHEM 123] about the scientist who wanted to know what does benzene look like. First he imagined, then he tested his theory. Imagination can help close the gap between what we don't know and what we learn.

Tayshawn shared, "We didn't see this [an atom]. It's so small. We have many techniques and experiments to understand the structure… There must be some experiments where they measure one thing and determine structure of atom." He went on to say:

> For example, in the [CHEM 123] lab, we do kinetics experiment and can see what the rate law is or in another experiment we measured absorbance but that tells us concentration so we are measuring one thing but determining another.

An awareness of the development of knowledge is an important component of epistemology, as described by many scholars (Baxter Magolda, 1992; Hammer & Elby, 2002; Hofer & Pintrich, 1997; Schommer, 1990).

Equipped with an awareness of the development of science, students transitioned into seeing science as a human construct, with uncertainty but evidence-based. In a focus group interview, Tayshawn claimed:

> Also in science there are some concepts that are created by the human. They do not naturally exist. You know what I mean? …For example, in today's class we learn Gibbs Free energy. We just define this term. It is not naturally in our world.

Dante described science as debatable, as opposed to absolute when he stated:

> Most stuff in science is not fact, we just assume…Also, scientists debate with each other. Today, [the CHEM 123 Instructor] mentioned that when dS < 0 some scientists say that this can become spontaneous but [the CHEM 123 Instructor] says she thinks differently.

Kevin added, "Science is self-correcting and not absolutely correct." This idea of science as "correct" or as "the absolute truth" was further explored during the one-on-one interviews. Students learn about Gibbs Free energy in CHEM 123 and perhaps, in high school. They can use the value of the change in Gibbs free energy, a theoretical concept, to predict whether a chemical reaction is spontaneous (Tro, Fridgen, & Shaw, 2013). Janet echoed Tayshawn's ideas when she stated:

> I don't feel like Gibbs free energy is truth. It is a way… we define it… like, in math when you define something… let me think. Everything we define is what we made. Truth is what was there without us.

In another interview Oscar made a similar claim, "Gibbs energy is set by humans, it does not exist by itself so it is only made by humans." Alen acknowledged science does not always lead to "true" theories and it is important to have the rationale behind a theory and not accept it without question and claimed:

> In high school, we took knowledge as the truth. And now we can see where it comes from… For example, integrals, we can just see that it is possible but now we can show it

> clearly. We are sure that it is true. Bohr model is wrong but now we can rationalize why it was wrong.

Students became articulate in understanding how scientific knowledge evolves. During the one-on-one interviews, I provided students with two different theories on Halogen bonding from two different peer-reviewed articles. All 13 students claimed they were not surprised there were two different theories because science is always changing and improving. All thirteen students said the chemists must be in the process of determining this phenomenon and more studies must be done. When I asked how they would evaluate which study was more accurate on describing halogen bonding, all thirteen students gave responses similar to Adam's when he stated:

> First, I would check the journal they publish. Whether the journal is well known or some unknown journal? A journal becomes popular if it is trustworthy so I would check which one is more well known using online. Also, I know some of the journals are peer-reviewed and some not. So if the journal is peer-reviewed, it means more than one scientist have proved this theory to see if it's true. Also, I would look at the author and see if [they] did a lot of experiment to prove [their] theory then I tend to trust [them].

Students' increased awareness of their own evolving understanding of science emerged as the one-on-one interviews progressed. For example, when asked to explain changes in answers to the EBAPS items, Albert alluded to this increased awareness:

> I changed my mind because… in this course, I know science is always changing. The textbook may be written 10 years before but science is always changing so maybe now the theory is not correct anymore.

Some students were careful to differentiate between science described as tentative versus untrue. For example, Kevin differentiated between established and current knowledge when he stated:

> For some laws, it will not change. Science is always changing- something new may be observed …In my mind, maybe previously scientists find this correct but in future we may see this is correct in some situation but not others.

Roya shared,

> After I finish this whole year, I see things are related. Even if it is false tomorrow, it is still related to another concept. A theory will change a little bit and won't be entirely wrong. There is a little bit of truth to every theory.

Students in the focus groups communicated how first year changed their views of the real-life applicability of science. Kavia expressed how her views changed when she claimed, "Here, you can actually go to class and understand everything. And real applications of a simple equation. For example, about conjugated systems give us colour." Fancy added, "SCIE 113 course influence my view. It always talk about applications of science and examples of how science help us so in my head I think of how science can be applied in life." White, Elby, Frederiksen, and Schwartz, (1999) describes viewing scientific knowledge and scientific ways of thinking applicable to real life instead of only in restricted spheres, such as a classroom or laboratory as an informed epistemology. Adam exemplified this transition when he said, "[in high school] we are not aware of chemistry in real life; we only use this word in school."

Students displayed a change in epistemological views of science between university and high school and also began to use more epistemologically informed ideas to describe scientific knowledge (Elby & Hammer, 2001; Hofer & Pintrich, 1997). When I asked what influenced their change in views of science, many students pointed towards courses and laboratory experiences. Dante claimed, "courses changed the way I think" and Kay responded to my question with, "Before I take SCIE 113, I didn't know scientists do research a lot and that their conclusions are not always correct. After the class, I learned scientists do research because they are curious and they don't have to have the answer right." Kavia pointed towards the laboratory experiences for influencing her, "In physics lab, we look at errors and look at limits of your results. What could go wrong so you can't actually say, this is the answer and this is true." Kay added, "In chemistry lab, we were taught that experiments can never prove your hypothesis, it can only support hypothesis so if you can't prove a hypothesis, there is no certain answer."

From the interviews, it is clear that the participating students expressed changes in their views of science, and these changes were geared towards a more informed or sophisticated epistemology. Studies in epistemology label views that knowledge is tentative, complex and not from an authoritative body as a "sophisticated" or "informed" view (Hofer & Pintrich, 1997; Schommer-Aikins & Easter, 2008).

5.2.2 Theme 2: Hard Work/Innate Ability as the Hallmark of Success

Most of the students who participated in the interviews viewed hard work as more important than any innate ability one may have to succeed in chemistry. Views of hard work/innate ability have to do with views of learning (For example, an individual can become better at learning through hard work), rather than knowledge (White et al., 1999). As stated in Chapter 2, I include beliefs about learning under the category of personal epistemology, following Elby (2009) and Schrommer (1990). Grace stated in her view of hard work over innate ability, “Yes, it hasn’t changed. For me, always hard work is most important.” Janet claimed:

> Hard work is really important. At some point your intellect won’t help you… like in Math class. If you are smart you may not have to do a lot of practice but that eventually the people who did a lot of practice got better.

Fancy agreed with Janet when she said:

> There is some example in my high school that most of the good student are not very intelligent but they study very, very hard and get good grades. Even though we know they are not smarter than others but study hard helps them get great grades, really great.

Chun asserted, “Hard work is 65% and natural ability is 35%... I have some friends who understand the whole class but they do not put effort into studying and their grades are not good.” Chun continued with, “I learned when I was young. I noticed this and read books like biographies- like Edison- Edison was not very smart but a hard worker.” Albert’s position was similar as he shared, “We know that old saying that person should have 99% hard work and 1% intelligence. When I was young, I heard some teachers say or parents also and my grandma always encourage me on my study.” Some students expressed that a consequence of working hard was achieving good grades. For example, Grace believed, “When I work hard, my score is better and when I don’t my score is lower. I think you know when you are doing hard work. Fancy echoed the statement with, “I found that if I work hard, it is not hard to get good grades.

But I don’t always work hard. If I work hard, then I can make things better and that makes me proud.”

It is possible that the student view of hard work being more important than innate ability is culturally driven. Chan and Elliot (2004) found in Asian cultures where Confucianism is a strong influence, views that science knowledge is attainable through hard work are more prevalent. This is different from North American cultures where students view innate ability as important to understanding science (Chan & Elliott, 2004). The majority of students interviewed are from Asia.

Two students, Oscar and Roya stated that innate ability was more important than hard work, and a few students voiced that both were important. As Roya stated, “I think every person in this stream must be hard working, otherwise they can’t be here but the difference between the grades is the intelligence.”

Of all the participating students in the interviews, only Roya and Jessy expressed that their views changed while at UBC. Roya stated, “Actually for me, it changed. Before I thought hard work. Now I think intelligence makes a difference.” Jessy stated:

> I think my perspective has changed since September. In September, I think that it does not matter how you study. Some people study hard but does not achieve a good grade. My view on hard work vs innate ability is always changing. For some situations, you need both intelligence and hard work.

It is clear that UBC Vantage One Science experience resulted in no change in a majority of the student views of hard work or innate ability as the hallmark of success.

5.2.3 Theme 3: Peer and Self-Learning are Considered Complementary Sources of Knowledge

How students interact with classroom activities such as peer learning has been shown to be related to a student's epistemology: "…student [epistemological] beliefs affect their involvement with particular tasks or in particular instructional settings" (Hofer, 2001. p. 373). Students who see their peers and themselves as an authority of science knowledge may have a favourable view towards peer learning, but students who view the instructor or textbook as the authorities of science knowledge may not support peer-based activities (Walker et al., 2009). McCaskey (2009) states, "If a student believes that knowledge in physics should come from a teacher or authority figure, and the class activities require more independent thought than direct intervention, there is epistemological conflict." (p. 2-3). I will first discuss my observations of how Vantage students reacted to peer learning in CHEM 121 and CHEM 123.

While students were observed to be heavily engaged during CHEM 123 group activities and did not often call upon the TAs or instructor, in contrast students who were provided with opportunities to work together on in-class worksheets in CHEM 121 chose to work on their own and asked the instructor or TAs for help. This changed over time as towards the end of term, I noticed some students teaching each other. Students also described something similar during the interviews, as Chun noted, "At the beginning, I was not comfortable asking a question to someone who is not close to me. Now, we got closer to each other so we participate." Most students agreed with Chun's comment that since they did not know each other very well in September, they were less willing to work together, but that slowly changed over the year. Tayshawn added to the conversation, "At the start of the year, we work together less because we know each other less and also the classroom we had in Chemistry 121 was kind of crowded and we cannot talk easily. Now, it is much easier." Chemistry 121 was taught in a traditional lecture-style classroom with fixed seating while Chemistry 123 took place in a classroom with moveable tables and chairs.

Students were highly engaged and on-task during peer learning activities in CHEM 123. This behaviour matched student claims on peer learning. During the one-on-one interviews, all 13 students spoke favourably about peer learning. Many saw peer learning as an effective strategy for learning, as Grace claimed:

> In fact we can learn a lot from others. We discuss together and some aspects I can not think about but others will think and it can provide a new way of thinking for me. For instance there is a question I will not think of using a formula but others can so I learn that.

Albert added, "Sometimes I don't know how to solve something and I can ask. Or sometimes when they don't understand, they can ask the group and I can also help. It is effective because we cover a wide range of problems." Jessy asserted in another interview, "Based on my own experience, when I teach my classmate a question, it helps me understand and have a deeper understanding. I also remember better." Other students saw peer learning as an important representation of collaborative work in science as stated by Roya, "Maybe chemists work with each other. Chemistry knowledge is large so I don't think one person can conquer it all so more likely they work in peers".

Many of the participating students came from high schools where there was an equal amount of peer learning as in CHEM 123 as Tayshawn described, "I would say same amount of peer learning in high school because I went to international school, and the teachers have certificate from BC." Many other students came from high schools where there was no peer learning at all. Students were asked what advice they would give themselves as they transitioned from high school to university and no student mentioned any advice around peer learning. For the students who had no peer learning in high school, I asked them why they would not have given themselves any advice about this new situation and in most cases, the response was because peer learning was easy to get used to. Oscar stated on his lack of advice, "I did not include peer learning or lab in my advice because it is not hard, I can figure it out." Chun echoed Oscar's comments, "I did not have peer learning in high school. It was easy to get used to." Some students stated that peer learning was not easy to get used to at the start but they saw the value of it as Kevin stated,

> When we work together, we can discuss. Everyone is involved in solving one question. It is very different from my high school. We rarely did that. This is effective. I think more people is better than 1 people. Other people can see mistakes. Peer learning is an important activity so I would advise to participate in more. I remember at the start in September I feel tired but then after long time, I found this can help me a lot.

Roya saw peer learning as valuable when she had difficulty with course content. She stated: "Maybe everyone like doing the problems on their own but now the material is more difficult so we talk more in groups."

Studies show that students would rather learn from an instructor than their peers (Felder & Brent, 1996). This finding indicates an epistemology where an authority is the source of knowledge and not the students themselves (Hofer & Pintrich, 1997). The Vantage students expressed a more sophisticated epistemology where they view themselves as a source of knowledge in addition to the instructor. During the one-on-one interviews, students were asked if they would prefer that an instructor solves a problem in class even if their peer knows the answer, and all thirteen said it was not necessary if their peer could explain the solution to the problem. Bowen summarized this discussion point: "If I know why or my friend explains why then I don't need instructor to go through it but if not, then I want instructor to go through it" Roya added, "I think this is enough that student tells me. I would want to know why. Every person has their own way to solve a problem. I prefer to learn from someone else than the instructor to solve problems."

Notably, although all thirteen students spoke favourably of peer-learning, their study logs indicated that outside of class, most students worked on their own and rarely work in groups. In the second one-on-one interviews, this discrepancy was explored. Their response stated that they did not work in groups outside of class because of convenience (it is easier to work alone at any time they want), and because they often became distracted when they work with others. Jessy explained her view: "I study by myself because it is more convenient. You can study whenever you want. Because I think I did the worksheet with my peer, I already have answer so I can just study by myself." Kevin also indicated working individually was more convenient but adds that he would contact peers when he needed help:

> Mostly I study by myself but for some difficult questions, I might find a partner or use a social chat. For me, in the evening efficiently by myself. If I go with other people, it may be distractive and we may talk about other things.

Some students alluded to the necessity of an authority or the pressure of an exam to stay on task to efficiently work in groups, as Fancy stated:

> I study by myself. Actually I learn from others but it is a bit noisy and it waste my time sometimes because it is too social. If someone is hungry, then we spend too much time outside. Yeah, I think so but peer study really help us a lot but if some students may just have fun so they need some pressure.

This is consistent with the findings of Boud (2014) who observed that peer learning is most effective when managed by faculty but tends to fall apart when students are left on their own to initiate and sustain peer learning (Boud, 2014).

5.2.4 Theme 4: Success in Problem-Solving Depended on Student Modes of Learning

The EBAPS questionnaire contained the following question: "When solving chemistry problems, knowing the methods or patterns for addressing each particular type of question is key. Understanding the "big ideas" or underlying concepts might be helpful for some problems, but not for most regular chemistry problems." Participants could choose between strongly agree and strongly disagree. The intention behind this question was to probe the student's underlying epistemology along the dimension of the structure of science knowledge. This dimension looks at whether an individual views science as consisting of facts and formulas to memorize or as a unified conceptual whole (White et al., 1999). A participant who views science as facts and formulas may agree with the statement in the EBAPS questionnaire (White et al., 1999). I asked participating students this same question from the EBAPS questionnaire during the one-on-one interview. Their response matched their problem-solving strategy in the subsequent task-based interviews. Students were given a chemistry problem in each task-based interview and asked to think aloud (Lising & Elby, 2005).

There were two task-based interviews. I created the problems and tasks based on my knowledge of first-year chemistry and common CHEM 123 student challenges. The first chemistry problem asked students that if acetic acid is added to water, is the dissociation of acetic acid spontaneous? The students were provided with the reaction of acetic acid in water and also provided with numerical data, including the standard change in Gibbs free energy value (Appendix A). This problem could be answered quickly without any calculations if one understands the concept behind the question. On the other hand, students might be tempted to use a particular 'method' or problem-solving pattern. Because this question has to do with an acid/base reaction, students who are pattern-driven might start using RICE (or ICE) method or start applying formulae to calculate some value but this will not lead to solving the problem. The RICE (or ICE) is a common method taught to students in high school and university chemistry courses when students are asked to determine concentrations of reactants or products in a reaction that is at equilibrium (Tro et al., 2013). One could solve the problem correctly based on experience (the reaction is a common reaction used in high school or university chemistry laboratories), or use the data provided and read the question carefully. No calculations were required but a simple calculation could have been used to clarify any student doubts about their answer. The second task-based interview had a similar set of problems where it may seem like a method could be applied, but all that was required was careful consideration of the question.

Student responses to the EBAPS question closely matched the approach they used on the task. Three students (Alen, Adam, and Albert) responded to the EBAPS question strongly favouring only “understanding the big ideas” and approached the problems using their conceptual understanding and were correct and quick at solving the problem. For example, Alen’s response to the EBAPS question was, "I think it is important to understand the concepts and apply the concept.” Alen answered the task-based question quickly and correctly using his conceptual knowledge (Appendix C). Four students (Tayshawn, Chun, Jessy, and Kevin) responded to the EBAPS question strongly favouring only “learning the method or pattern”. These four approached the problem trying various formulas and methods and ended up confusing themselves and were not able to solve the problem. For example, Tayshawn responded to the EBAPS question by stating, “It is better to know the method because there is not much conceptual questions in chemistry exam. Mostly, we need formulas and how to apply for questions.” Tayshawn reacted to the task-based problem by writing formulae that he thought related to the question. When that was unsuccessful, Tayshawn then drew a RICE table and tried the question and he was still not able to solve the problem. He then went back to formulae related to buffers (the question is not about a buffer). Ultimately, he was not able to solve the problem (Appendix C).

Students who favoured both patterns and big ideas landed in the middle; some used conceptual understanding to approach the problem, and some took to a pattern or they tried pattern first and moved to the conceptual. I have summarized student self-reported views on conceptual understanding versus pattern-driven and how they mapped with a strategy that the student used to solve the think-aloud tasks in Table 5.1. In Appendix C, I have included the specific quotes and problem-solving strategies with each student's response as well as an example behaviour from the first task-based interview. For most students, their behaviour was consistent between task 1 and task 2. I identified the cases where the behaviour was largely different between the two tasks in Table 5.1.

Classification of Student Expressed view	Student	Student problem-solving strategy
Favored conceptual understanding	Alen	Highly conceptual
Favored conceptual understanding	Adam	Highly conceptual
Favored conceptual understanding	Albert	Highly conceptual (looks at equation but to confirm concept)
Favored both	Janet	Starts with patterns then applies concepts.
Favored both	Fancy	Inconsistent between tasks. Uses both patterns and concepts.
Favored both	Grace	Highly conceptual
Favored both	Oscar	Inconsistent in tasks. Used both concepts (although not fully) and patterns.
Favored both	Bowen	Uses both patterns and concepts. In task 1, used concepts and was successful but in task 2 used patterns and got lost. She admits that she does not know the concepts at the end of the task.
Favored both	Roya	Uses both patterns and concepts. In task 1, used patterns and got lost but in task 2 used concepts and succeeded.
Favored patterns	Kevin	Uses only patterns and got lost quickly.
Favored patterns	Jessy	Uses only patterns and got lost.
Favored patterns	Chun	Uses only patterns and got lost.
Favored patterns	Tayshawn	Uses only patterns and got lost.

Table 5-1: Summary of Participating Student Views on Problem Solving and Problem Solving Behavior

The students' problem-solving behaviour suggests an underlying epistemology that matched student responses to the one question in which the intention behind the question was to probe student epistemology on the structure of science (formula-driven versus conceptual). The data suggest students' successful completion of a conceptual problem in chemistry was related to whether the student views conceptual understanding of a problem as more important than pattern-matching approach. These findings are consistent with prior literature that suggested a link between epistemology and behaviours related to learning (Hofer, 2001; Kalman et al., 2014; Lising & Elby, 2005).

5.3 Summary

The following four themes are evident from the interview data:

1. Changes in epistemologies in post-experience conversations
2. Hard work/innate ability as the hallmark of success
3. Peer and self-learning are considered complementarity sources of knowledge
4. Success in problem solving depended on student modes of learning

The qualitative data suggest participating students changed their views of science and these changes were towards a more informed or sophisticated epistemological view. Specifically, participating students expressed an increased awareness that science is complicated because it is a human construct, has uncertainty, and is evolving and applicable to real life. Further, students were now able to describe how scientific knowledge is developed and ways to evaluate differing theories of science. Students reported that their change in views were due to course work at UBC, including labs and lectures. Participating students generally held the view that hard work is more important than innate ability for learning. This view was generally formed before coming to UBC and mostly, did not change while at UBC. Peer learning was favoured by participating students as an effective technique in the classroom because students viewed their peers and themselves as sources of knowledge. A connection was found between underlying epistemology of student problem-solving strategies and student responses as to whether they favoured knowing underlying concepts versus problem-solving patterns. Students who held a strong view that favoured knowing the underlying concepts, correctly completed the problem solving task and students who held a strong view that they favoured knowing the patterns for solving problem types were unsuccessful at completing the problem solving tasks. Students who favoured both exhibited problem-solving strategies that varied between the two extremes. This finding suggests that having an expressed formula-driven view to problem solving negatively affects problem solving behaviour.

I have now presented the qualitative data analysis. In chapter 6, I will discuss the findings that emerged after comparing the quantitative results from Chapter 4 to the qualitative results from this chapter.

Chapter 6: Discussion and Conclusions

In this chapter, I relate the results from the quantitative and qualitative data and look for collaborations to form new variables (Cresswell et al., 2003). I will answer my research questions, discuss the limitations of the study and propose areas for future research. The final section will include a conclusion of my dissertation. First, I will review in Table 6.1, the study's important quantitative (Chapter 4) and qualitative (Chapter 5) findings.

Chapter 4: Quantitative Analysis	Chapter 5: Qualitative Analysis
• The overall mean scores for the questionnaire indicate a statistically significant change ($p < 0.01$) from $Round_{SEPT}$ and $Round_{JULY}$. • One-way repeated measures ANOVA indicates that the overall mean scores are significantly different between $Round_{SEPT}$ and $Round_{JULY}$ ($p = 0.05$). This score implies student experienced some change in epistemologies over time. • Confirmatory factor analysis (CFA) indicates that $Model_{EBAPS}$ was not statistically significant for describing the factor structure of any of the three rounds. • Exploratory factor analysis of each round yielded three different dominant factor structures, suggesting change in epistemologies. • CFA indicate that $Model_{SEPT}$ is the better fit for three rounds compared to the other models. • Descriptive analysis of $Model_{SEPT}$, CFA and one-way repeated measures ANOVA indicate that there was a transformation of $Model_{SEPT}$ over time. In particular, descriptive analysis points to a high probability that students held different views in their overall epistemologies and views on "Authorities of Science Knowledge" and "Confidence in Understanding Science" as compared to the start of the program in September 2015. One-way repeated measures ANOVA suggests that students held statistically significant different views in the factor, "Confidence in Understanding Science" after 8 months of the program as compared to the start of the program. Examining the standard errors of regression weight estimates in CFA of $Model_{SEPT}$ applied to $Round_{MAY}$ indicates that factor "Absolutism in science" was not a dominant epistemology factor in $Round_{MAY}$. This indicates that some epistemological factors that were dominant in $Round_{SEPT}$ were no longer dominant over time. • The factor, "Confidence in understanding science" from $Model_{SEPT}$ is the factor that is most correlated with both CHEM 121 and CHEM 123 grades and the correlations are "moderate". Laboratory activities in both CHEM 121 and CHEM 123 experienced correlations with the most epistemological aspects.	• Participating students expressed changes in their epistemologies and attribute some of these changes to their coursework. • Participating students are expressing an increased awareness that science is complicated and describe it as a human construct with uncertainty, as evolving, and as applicable to real life. Further, students are now able to describe how scientific knowledge is developed and ways to evaluate differing theories of science. • Participating students expressed a prior view that hard work is more important than innate ability, which did not change for most students. • Peer learning in class was favored by participating students as an effective technique in the classroom because students viewed their peers and themselves as sources of knowledge. • A connection was found between underlying epistemology of student strategies during problem solving and student responses as to whether they favored knowing underlying concepts versus problem-solving patterns.

Table 6-1: Summary of Key Findings from Quantitative and Qualitative Analysis

6.1 Results

Consistent with a "Concurrent Triangulation Mixed Methods Design, the outcomes from the quantitative analysis in Chapter 4 were related to the qualitative themes in Chapter 5 and explored for associations (Cresswell et al., 2003). I looked for manifestations of revelation from the quantitative analysis of EBAPS scores in the qualitative data. Whenever possible, I corroborated the quantitative results with the qualitative results and offset any weakness of one method with the strengths of the other. The results are four new themes identified from these collaborations:

1. **The students' epistemological dispositions influenced their academic achievement and/or performance.**
2. **The students' epistemologies became more canonically disposed over time.**
3. **Pedagogy and student epistemological change are not independent of each other.**
4. **Characterization of transformations in epistemologies is more effectively done through qualitative research.**

The following is a discussion of these emergent themes.

6.1.1 Theme 1: The Students' Epistemological Dispositions Influenced their Academic Achievement and/or Performance

Correlation analysis indicates that the scores from the factor, "Confidence in understanding science" from $\text{Model}_{\text{SEPT}}$ at the student's entry of the program ($\text{Round}_{\text{SEPT}}$) was significantly correlated with achievement measures such as the final exam in both CHEM 121 and CHEM 123. This is consistent with other research where self-efficacy, defined as perceived confidence in performing class work, was directly correlated to academic achievement (Pintrich & de Groot, 1990). In another study, a statistically significant correlation was found to exist between students' science achievement and their science self-confidence and interest with a moderate effect size (Chang & Cheng, 2008). In Chang and Cheng's (2008) study, student achievement was measured using a high-stakes test that screened high school students entering into different ranks of universities. The students' self confidence in science was measured using the Inventory of Self Confidence and Interest in Science (ISCIS) survey. A third study found a statistically significant correlation between confidence in problem solving and conceptual understanding of physics, as measured by the Forced Concept Inventory (FCI) (Milner-Bolotin, Antimirova, Noack, & Petrov, 2011). The findings of this study adds to the current body of work, echoing the importance of student confidence in learning science to their academic performance.

Correlation analysis also points towards a relationship between multiple aspects of epistemology from Model$_{SEPT}$ and academic achievement in the CHEM 121 and CHEM 123 laboratory. This finding suggests that, compared to other course assessment measures, achievement in the laboratory is most influenced by a student's underlying epistemologies. The connection between the laboratory and epistemologies is further explored in section 6.1.3. Relationships indicated by correlation analysis were difficult to corroborate with the qualitative data due to limited interactions between the researcher and students at the start of the year as I was teaching the students at that time.

The task-based interviews pointed towards a direct connection between student epistemological dispositions and their problem-solving performance. During the tasks, students either took an approach that was consistent with viewing chemistry as formula-based and with un-connected pieces of information, or they used an approach that viewed chemistry as coherent and conceptual or a balance between both extremes. A view of chemistry as coherent led to greater success at solving the problem. Similarly, Hammer (1994) found a connection between characterization of student beliefs about knowledge and student work in an introductory physics course including problem-solving. The data suggest that students' successful completion of a conceptual problem in chemistry is positively linked to the student view that conceptual understanding is more important than pattern-matching approach.

Qualitative data indicate that student study strategies changed over time. This result may be linked to both epistemology and academic achievement. Schommer (1993) hypothesized that epistemological beliefs might affect student selection of study strategies, and these strategies might influence academic achievement (Schommer, Crouse, & Rhodes, 1992). In the one-on-one interviews, students reported that over time, their approach to learning changed. When asked to specify how their learning changed, students reported they did less memorization and instead, attempted to understand the origins of knowledge. Michael stated, "In high school, we need to remember lots of formulas and facts. At UBC, we know how to apply formulas and need to have a deeper understanding. Tayshawn added, "[In high school] we did not have to read the book. Here we have to read and self study then come to class and ask questions." These findings are consistent with the literature which provides evidence that as students develop more informed epistemologies, they develop better study strategies and attain better academic achievement. For example, students who view knowledge as absolute truth are content with adopting study strategies that call for wrong or right answers. Hence, instead of constructing their own understanding, they study for memorization (Pulmones, 2010). Students who view knowledge as complex, tentative, and evolving see themselves as the source of this knowledge as they collaborate with others in their construction of knowledge (Pulmones, 2010). This behaviour was indicated in the one-on-one interviews as Alen stated:

> "In high school] instructor just told us what to do. At UBC, the instructor is like an advisor. They are flexible and try to get us to figure out the answer. Role of the student is that it is my choice; I have to be self-motivated and self-study. I study better and feel more free now."

The findings from this study are consistent with the literature as they imply that fostering epistemological growth and confidence in science learning in first-year students may lead to positive gains in academic achievement, performance and study strategies.

6.1.2 Theme 2: The Students' Epistemologies Became More Canonically Disposed Over Time

As discussed in Chapter 2, Section 4, "more sophisticated epistemology" is described in the literature in a constructivist sense to be an epistemology that is more informed (Deng et al., 2011; Elby & Hammer, 2001; Hofer & Pintrich, 1997). But, characterizing scientific epistemologies as "sophisticated" (and "informed") without contextualizing the use of the terms is problematic (Elby & Hammer, 2001). The term "sophisticated" or "informed", when used in reference to scientific epistemology, tends to describe a view that is more scientifically oriented and adheres to the canons of science. The underlying assumption is that more exposure to scientific reasoning would be grounded in canonical paradigms of science and hence the use of "informed" in characterizing student epistemologies. Thus, in the discussion that follows, I will use "more canonical" to characterize views consistent with scientific paradigms (Kuhn, 1962). This includes the recognition that while subjectivity is un-avoidable, science aims to be objective and while science can be described as tentative, it can also be established, depending on context (Elby & Hammer, 2001). Furthermore, while science knowledge is created from imagination, it is also created from logical reasoning (Liang et al., 2008).

The factor structure models over time (Table 6.2), and the qualitative data point towards the students as a cohort developing a more canonical epistemology. The factor structure models are based on variability of EBAPS scores, not raw scores (Furr & Bacharach, 2013). I will first discuss the factor structure models over time and then map those findings to the qualitative data.

Conceptual Interpretations of the Factors		
Model$_{SEPT}$	**Model$_{MAY}$**	**Model$_{JULY}$**
1. Success in science as a function of hard work or natural ability 2. Authorities in Science 3. Confidence in understanding science 4. Absolutism in Science 5. Learning Science in the Classroom	1. Multiple Perspectives about success in Science 2. Doing well in Science 3. Awareness of the Structure of Scientific Knowledge (Pieces vs whole) 4. Awareness of the complexity in Science 5. Problem-solving in Science (classes)	1. Doing well in Science 2. Success in science as a function of hard work or natural ability 3. Awareness of Self in Science 4. Learning about Science

Table 6-2: Table from Chapter 4; Colored Highlight Signifies the Same Factor.

At the start of the program in September 2015, students seem to focus mainly on science as a classroom endeavour rather than have a broader perspective of science. Factors 1 (Success in science as a function of hard work or innate ability), 3 (Confidence in understanding science), 4 (Absolutism in science) and 5 (Learning science in the classroom) are all related to learning science in a classroom situation (Factor 4 contained items related to test questions or textbook materials). Factor 2 (Authorities in science) is broader and more related to epistemology (Hofer & Pintrich, 1997). The presence of factors preoccupied with classroom situations is consistent with literature. At the start of university, students tend to hold less canonical views of knowledge (Baxter Magolda, 2006) and see their education as isolated to the classroom (Hammer & Elby, 2002). This is also consistent with qualitative data discussed in Chapter 5 as students indicated they viewed science as isolated to the classroom in high school, but in university they realized science to be much more broad. This finding emerged during the focus groups in January 2016, when students were asked to compare high school science with university as Kavia reported:

> It completely changed. I didn't like chemistry. I saw chemistry as balancing equations/reactions or what is the concentrations. I never got into why. I thought it was just memorize. Here, you can actually go to class and understand everything. And real applications of a simple equation. For example, about conjugated systems give us color.

Shing added, "Here you study to seek knowledge, not just for tests."

In both May 2016 (8 months after the start of the program) and July 2016 (11 months after the start of the program), the factors from September 2015 became less dominant and new factors emerged. Students were still concerned with science as a classroom endeavour but there is also evidence students became more aware of the nature of science knowledge. In Round$_{\text{MAY}}$, Factors 1 (Multiple perspectives about success in science) and 2 (Doing well in science) are both related to science as a classroom endeavour. On the other hand, Factor 3 (Awareness of the structure of scientific knowledge; pieces versus whole), Factor 4 (Awareness of the complexity in science) and Factor 5 (Problem-solving in science) suggest an enhanced awareness of the nature of science. By May 2016, the students had experienced two semesters of peer-based and interactive science (Chemistry and Physics) courses.

In July 2016, two of the four factors that dominated are related to science as a classroom endeavour. Factor 1, (Doing well in science) is a persistent factor from $\text{Model}_{\text{MAY}}$, and Factor 2, (Success in science as a function of hard work or natural ability) is a persistent factor from $\text{Model}_{\text{SEPT}}$. Factors 3 and 4 from $\text{Model}_{\text{JULY}}$ suggest the students are showing signs of a deeper understanding of science. Factor 3, (Awareness of self in science) points towards the awareness that personal interpretations and oneself as a source of knowledge has a role in science. Factor 4, (Learning about science) contains items that look at learning science both in a classroom context and beyond.

The factor structure analysis of $\text{Round}_{\text{MAY}}$ and $\text{Round}_{\text{JULY}}$ is consistent with the interview data discussed in Chapter 5; Participating students expressed an enhanced awareness of the nature of science. Students viewed science as more complicated, applicable to real-life and not just in the classroom, and evolving, and they had a deeper understanding of how science knowledge is developed and evaluated. As Albert claimed, “I changed my mind [between September and July) because …I know science is always changing. The textbook may be written

10 years before but science is always changing so maybe now the theory is not correct anymore. Roya added to the conversation:

> I think I changed because in September, I think everything is changing in this world. After I finish this whole year, I see things are related. Even if it is false tomorrow, it is still related to another concept. A theory will change a little bit and won't be entirely wrong. There is a little bit of truth to every theory. It is not completely settled but it is somewhat. Not all the things are very easy to be checked totally.

Kay shared:

> Before, I didn't know scientists do research a lot and that their conclusions are not always correct. After the class, I learned scientists do research because they are curious and they don't have to have the answer right.

In conclusion, there is evidence to indicate that students developed more canonical epistemology. Specifically, they began to see science as broader than a classroom endeavour and began to understand how science knowledge is developed and evolves. The data also suggests that students developed more canonical epistemologies with respect to sources of knowledge, which will be discussed further in the next section.

6.1.3 Theme 3: Pedagogy and Student Epistemological Change are Not Independent of Each Other

This study indicates that pedagogical approaches are key influences on student epistemologies. Professors of international students often report that international students do not participate in class, and they perceive the reason as being due to the students' culture (Andrade, 2006). Liberman (1994) reported that Asian students studying in the United States experienced difficulty adjusting to the peer learning style and critical thinking approach to learning. Based on these studies, one may predict that the Vantage One Science students would have difficulty in CHEM 121/123 lectures where peer-learning was encouraged. As discussed in Chapter 2, the partial flipped classroom used in CHEM 121 contains a peer-learning component and CHEM 123 used peer-instruction.

The quantitative data point towards students as a cohort transformed their epistemology towards one more supportive of peer learning. In $\text{Model}_{\text{SEPT}}$, dominant factor included "Authorities in science" but in $\text{Model}_{\text{JULY}}$ a dominant factor included, "Awareness of self in science" (Table 6.2). Students who view the instructor or textbook as the authorities of science knowledge may not support peer-based activities (Walker et al., 2009). Thus, in September, when the dominant epistemology focused on who or what is the authority, students were less likely to engage with peer learning. McCaskey (2009) states that, "If a student believes that knowledge in physics should come from a teacher or authority figure, and the class activities require more independent thought than direct intervention, there is epistemological conflict."(p. 2-3). On the other hand, students who see their peers and themselves as an authority of science knowledge may have a favourable view towards peer learning (Walker et al., 2009).

The quantitative findings are consistent with the findings from the interviews. As discussed in Chapter 5, all 13 students spoke favorably on peer learning during the one-on-one and focus group interviews and researcher observations and student comments indicate that students became fully engaged with peer learning throughout the program. During the one-on-

one interviews, students were asked if they would prefer that an instructor solve a problem in class even if their peer knows the answer. All 13 participants responded that it would not be necessary if their peer could explain the solution to the problem. For example, Roya stated, “I think this is enough that student tells me. I would want to know why. Every person has their own way to solve a problem. I prefer to learn from someone else than the instructor to solve problems.”

An apparent lack of student resistance to peer learning may be explained by the uniqueness of the Vantage One Science Program. First, as described in Chapter 5, the students complete their first year courses as a cohort so there is opportunity for students to know each other and become more comfortable with peers. Second, the Vantage program encourages alternative teaching methods to traditional style (“UBC Vantage College,” 2018) so multiple courses use peer learning. Classroom cultural norms are created with repeated use of practices (Turpen & Finkelstein, 2010) and instructor cues have an impact on student engagement with peer learning (Knight, Wise, & Southard, 2013). Thus, students are receiving similar messages with respect to peer learning from multiple instructors, and these messages are likely to contribute to their views on the value of peer learning.

Correlation analysis suggests that performance in the chemistry laboratory was correlated to multiple factors of $\text{Model}_{\text{SEPT}}$ while other course assessments were correlated to one factor. As described in Chapter 2, first year chemistry laboratory at UBC uses a guided inquiry approach (Minner et al., 2010). Guided inquiry based learning in CHEM 121/123 laboratory means that students are not given answers (such as answers to how the procedure should be written), but instead students are provided with a great deal of support in the form of online resources, laboratory manual, and access to instructors enabling them to find the answer themselves. Student learning is also carefully monitored through formative assessments of student produced work, such as the student written procedure and in-lab observations (Nussbaum, 2015). It is not surprising correlation analysis suggests a connection between multiple aspects of epistemologies and performance in the inquiry-based first-year lab because the nature and production of knowledge are at the heart of inquiry (Sandoval, 2005). Inquiry has been described as a way to develop epistemological understanding of science and the development of science (Abd-El-Khalick et al., 2004). At least one student credited their enhanced awareness of uncertainty of science to inquiry-based laboratory. According to Kay: “In chemistry lab, we were taught that experiments can never prove your hypothesis, it can only support hypothesis so if you can’t prove a hypothesis, there is no certain answer.”

Inquiry is also central to the model of undergraduate education put forward by Baxter Magolda as the means to support students on their developmental journeys towards ‘self-authorship’ (Baxter Magolda, 2004). Self authorship is a position of epistemological maturity characterized by awareness of knowledge as constructed and belief in oneself as possessing the capacity to create new knowledge (Baxter Magolda, 2004). During the interviews, there was some indication that students may be at the start of a journey to self-authorship due to the guided-inquiry pedagogy of the chemistry laboratories. For example, Adam stated, “Seeing the reaction is kinda fun. I also like the course here is different from high school because it gives me more a chance to think.” Kavia expressed appreciation that, “in this term they (CHEM 123 labs) gave us the freedom to develop your own experiment.” Students noticed the difference in pedagogy and were able to link it to their own approaches to learning. For example, Tayshawn observed, "In lab, before, we follow a procedure and report a result. This term, we create our own procedure and bring our own samples...to promote self-study." Researcher observations of the CHEM 123 laboratories indicated that the Vantage One Science students seemed comfortable in the unstructured laboratory. This is a somewhat surprising finding since there is a strong reliance on English-language reading comprehension for students to come up with their own experimental procedure (Nussbaum, 2015). Students did not report difficulty with this task perhaps because the CHEM 121/123 laboratory also provides visual representations of each lab. Studies have implicated the importance of content-embedded visual representations for English Language learners in inquiry-based laboratories (Manavathu & Zhou, 2012). Observations also indicated that Vantage One Science students relied on their peers in the laboratory. There was a considerable amount of checking in with peers, which is consistent with the finding that this population values peer learning. The finding that guided inquiry-based learning is connected to epistemologies is consistent with the literature. Progressing from a more structured, "cookbook" laboratory environment to one of less structure and more inquiry can encourage personal epistemological growth (Mazzarone & Grove, 2013).

6.1.4 Theme 4: Characterization of Transformations in Epistemologies is More Effectively Done Through Qualitative Research Methods

Both qualitative and quantitative analysis point towards some transformations in epistemology in this study. The mean epistemology scores as measured by EBAPS showed statistically significant *decrease* for overall epistemology and for some factors identified in $Model_{SEPT}$ which suggests epistemologies became less canonical over time. However, detailed semi-structured interview data of 13 students suggest that the participating student epistemologies became *more canonical*. In this situation, the interview data should be trusted (Baxter Magolda, 2006; Elby & Hammer, 2001). In fact, historically, most of the research of student epistemologies used interviewing and observations (Baxter Magolda, 1992; King & Kitchener, 1994; Perry, 1970). Scoring and labelling a questionnaire response as more or less canonical is problematic as identified by Elby and Hammer (2001). Elby and Hammer (2001) suggest that epistemological assessments “mis-measure” students’ epistemological stances because the assessments rely on generalizations and do not attend to context: “Interviews have a better chance of uncovering the contextual dependencies—and hence, the true sophistication—of students’ beliefs about knowledge” (Elby & Hammer, 2001 p. 3). In fact, Elby and Hammer (2001) are critical of their own EBAPS survey which was used in this study:

> Consider this item from the Epistemological Beliefs Assessment for Physics Science (White et al., 1999): When it comes to controversial topics such as which foods cause cancer, there’s no way for scientists to know which scientific studies are the best. Everything’s up in the air!
>
> A student could agree with this statement because she has entered a philosophical (as opposed to practical) mode, or because she suspects that subtle methodological flaws invalidate recent epidemiological studies. By contrast, her agreement could reflect her belief that all statistics lie, that controlled experiments are less compelling than graphic anecdotal evidence, and that astrology is a better sources of knowledge than science is. So, a knowledge-is-tentative response may reflect sophisticated or naïve reasoning. (p. 7)

There was evidence of this issue where contextual understanding of an EBAPS question led to a mis-characterization of epistemology. During the one-on-one interviews, I asked Oscar why his response to the EBAPS item, “I should put everything in my own words” changed from Round$_{SEPT}$ to Round$_{MAY}$. In Round$_{SEPT}$, Oscar agreed that it was beneficial to put everything in his own words but not in Round$_{MAY}$. Oscar explained that to him, “my own words” meant translating everything to Chinese. This was the strategy he used when he first came to UBC, but he later realized it was a futile exercise because some words did not translate well. Oscar explained that he should just learn the meaning of the English terms. This example clearly indicates that although Oscar’s survey response would be scored as less canonical between Round$_{SEPT}$ and Round$_{MAY}$, his reasoning to justify his answers have little to do with a more or less canonical epistemology.

Another limitation of using surveys for labeling responses as more or less canonical is that questionnaires rely on generalizations about the nature of knowledge and learning. The results from the questionnaire indicated mean student scores decreased (became less canonical) between Round$_{SEPT}$ and Round$_{May}$. In the interviews, I inquired into this result during the May focus group interviews for possible explanations and it was revealed the students became more aware of what is basic research as they realized that science does not need to have real-life applicability in order to be valuable. Dante explained his view:

> Is all the people you surveyed Vantage students? I think it is because we all took SCIE 113 because we surveyed research professors in one assignment and asked them question about why they do the research. Most of them said they do it because they are curious and most of their research, they fail. If they did it correctly, they may not know how it apply

> to real life.. it may not be for another 50 years that is will apply to real life so its not very applicable.

Kevin added:

> Some concepts are in basic science. But the scholar in basic science will not think about how it is apply. Even in [Math] class, they told us to prove a rule (where a rule comes from), not only use the rule but in applied sciences classes, they just use the rule and don't care where it comes from.

Other students explained they now viewed science as more theoretical and engineering as applied. Jiawei stated, "In science we learn about the theory. In engineering, they think about applications." Based on the interview data, students were becoming more canonical in their view of science, recognizing that science does not have to be applicable to be valuable. However, the scores on EBAPS survey reflect less canonical views because the questionnaire is trying to measure whether students see the value of science outside the classroom and in their real lives.

The use of surveys to assess epistemology has been on the rise since Schommer developed her survey in 1993 (Hofer & Pintrich, 1997). Based on the limitations of epistemology surveys that have manifested in this study, a recommendation for future epistemology research would be to employ a mixed methods approach where there is the opportunity to support the weaknesses of surveys with observational and/or interview data.

6.2 Answers to Research Questions

In this section I will summarize key findings in reference to the research questions outlined in Chapter 1.

6.2.1 Answer to Research Question 1

What are the personal epistemologies evident among first-year international UBC Vantage College undergraduate students in the Vantage One Science Program at the beginning and the end of Chemistry 121 and Chemistry 123?

Students held both non-canonical and canonical epistemologies simultaneously throughout the 11-month Vantage One Science program. This finding is predictable, given that many students are from non-Western countries. There may be cultural clashes between students' life-worlds and the world of Western science which can lead to students holding conflicting concepts about science learning (Aikenhead & Jegede, 1999; Herbert, 2008). The mechanism by which a student reconciles these conflicting concepts in science learning is defined as collateral learning (Jegede, 1995). For example, one such mechanism could be for an individual to have an awareness of conflicting concepts but to also have adequate reasons to maintain both concepts (Herbert, 2008).

Quantitative analysis including factor analysis of the EBAPS questionnaire administered at $Round_{SEPT}$, $Round_{MAY}$ and $Round_{JULY}$ provides characterization of the dominant aspects of epistemology present at each round. This is summarized in Table 6.2. At the start of the program in September 2015, students held less canonical views, such as seeing science as a classroom endeavour, as right/wrong and seeing scientific knowledge residing in external authority. At the same time, students held a more canonical view that hard work is more important than innate ability in acquiring scientific knowledge. This characterization of $Round_{SEPT}$ is consistent with qualitative data discussed in Chapter 5 as students indicated that out of high school, they viewed science as isolated to the classroom, as absolute, and that hard work is more important than innate ability. In addition, observational data indicated that, at the start of university, students looked towards the CHEM 121 instructors instead of their peers as sources of knowledge.

As the program progressed, dominant epistemologies still include less canonical views of science as a classroom endeavour as factors related to this topic emerged in both May and July 2016 (Table 6.2). At the same time, students became more aware of the development and structure of science knowledge, which emerged as a dominant aspect of epistemology in May 2016 (Table 6.2). This is also consistent with the qualitative data as students expressed an increased awareness that science is complicated because they start to understand how scientific knowledge is developed. Students began to view science as a human construct with uncertainty, as evolving, justifiable, and as applicable to real life. Students identified their coursework as one reason for their change in views. Students also expressed a more canonical view of oneself and peers as a source of knowledge in science. This view maps well onto the quantitative data with a dominant factor emerging in July 2016 labelled as "Awareness of self in science" (Table 6.2; Factor 3).

The non-canonical epistemologies held by students at the start of the program are mainly consistent with other studies (Abd-El-Khalick, 2006; Baxter Magolda, 2006; Louca et al., 2004). On the other hand, the transformations towards more canonical epistemologies that occurred during the 11-month program seem to be unique to this context and population. Epistemological transformations generally occur over longer periods of time (Baxter Magolda, 1992; King &

Kitchener, 1994; Perry, 1970) and may not be expected to occur for international student populations unless there is a strategic intervention (Aikenhead & Jegede, 1999; Andrade, 2006). Epistemological transformations and the impact of the Vantage One Science Program on student epistemologies is further discussed in the remaining sections.

6.2.2 Answer to Research Question 2

How are these personal epistemologies affected over the 11- month period in the program?

This study indicates that some aspects of epistemology are more susceptible to change while others are not. From the quantitative analysis, the factor structure of $\text{Model}_{\text{SEPT}}$ was analyzed for changes over time using descriptive statistics, one-way repeated measures ANOVA and CFA. From the qualitative analysis, students indicated changes in epistemologies in terms of viewing science as more complicated, as having uncertainty, applicable to real-life, and tentative. Students had an enhanced awareness of how science knowledge is developed. These conceptions are related to the factor, “Absolutism in science” from $\text{Model}_{\text{SEPT}}$ (Table 6.2) which was detected by CFA to change over time. “Absolutism in science” probes the extent to which students navigate between seeing science as unchanging, right/wrong, and seeing science as having limitations. On the other hand, students expressed a prior view that hard work is more important than innate talent during the interviews, which did not change for most students. This conception maps onto the factor, “Success in science as a function of hard work or natural ability” from $\text{Model}_{\text{SEPT}}$, (Table 6.2) which was not detected to change.

The qualitative data suggest that aspects which have been clearly expressed, entrenched for long periods of time, and are valuable to the students would be less susceptible to change.

Aspects that are less established for a student and those that are targeted by the learning experience is more likely to change. During the interviews, students had a clearly expressed view of whether hard work or innate ability was important, which they identified to have before coming to UBC. In fact, students passionately argued with one another about this topic during the focus group interviews which indicates that students attached value to this view. As discussed in Chapter 5, some students, such as Albert and Chun, indicated they held this view for a long period of time. In contrast, an epistemological factor that was not well established and one that is targeted by the Vantage One Science Program was more easily susceptible to change. For example, in many cases discussed in Chapter 5, students communicated that before coming to UBC, they had a lack of awareness of how science knowledge is developed, its real-life applicability and evolving nature so their initial perspectives were more susceptible to change. Fancy stated that, "In China, my teacher tells us the content of science. I don't know how the scientists get it."

This study also suggests that unique components of the Vantage One Science program led to transformations in epistemology. These components include pedagogy reliant on peer learning and guided inquiry-based learning and course content. In addition to chemistry content of CHEM 121 and 123, students identified SCIE 113 as a course that influenced their view. SCIE 113 is a required course for Vantage One Science Program which explicitly discusses the nature of science including topics such as the tentativeness of scientific knowledge and how scientific knowledge is created. Since all Vantage One Science students are required to take this course, the program targeted these specific epistemology factors. It is not surprising then, that change occurred. This is consistent with literature as Lederman argues that an explicit approach is more effective than an implicit approach when learning about the nature of science (Abd-El-Khalick & Lederman, 2000).

6.2.3 Answer to Research Question 3

How are these personal epistemologies implicated in student academic performance, study approaches and views of pedagogy used in first-year chemistry?

This study suggests that more canonical epistemologies are associated with positive problem-solving strategies, academic achievement and study strategies. The study also found that student views of active learning pedagogy used in first-year chemistry improved over time. During the task-based interviews, students who expressed a view that conceptual understanding is more important than pattern-matching solved the chemistry problem using a more conceptual approach. A conceptual problem-solving approach is consistent with a more canonical epistemology that chemistry knowledge is coherent, conceptual and highly-structured (White et al., 1999). Correlation analysis suggests the epistemology scores from the factor, "Confidence in understanding science" from $Model_{SEPT}$ at the student's entry of the program ($Round_{SEPT}$) was correlated with course assessments such as the final exam in both CHEM 121 and CHEM 123 lectures. Correlation analysis also indicates that achievement in the chemistry laboratory was affected by multiple aspects of $Model_{SEPT}$. Qualitative data indicate student study strategies changed over time which may be linked to both epistemology and academic performance. In the one-on-one interviews, students reported that over time, they did less memorization and instead, attempted to understand where knowledge came from.

Student views of active learning pedagogy in first-year chemistry improved over time. Observations indicate that students were more engaged with peer learning pedagogy as time went on and this behaviour corresponded with transforming epistemologies toward viewing peers and oneself as a source of knowledge. Some students expressed they found peer learning challenging at first, but they quickly recognized the value and felt comfortable. Students articulated very positive views of the peer learning used in CHEM 121 and CHEM 123 lectures during the interviews held in January, May and July. This is consistent with quantitative data which highlight that in September, when a dominant epistemology focused on who or what is the authority (Table 6.2), students were less likely to engage with peer learning, but in July, the dominant epistemology included “Awareness of self in science”. This transformation also appears to have manifested in student behaviours in, and student views of, the CHEM 123 laboratories. During the focus group interviews, students expressed appreciation for the guided inquiry-based approach in the CHEM 123 laboratories because they enjoyed being more independent in their own learning. Some students viewed the pedagogy in the chemistry laboratories as promoting self-study. Researcher observations of the CHEM 123 laboratories indicated that students looked comfortable in the unstructured environment and relied on their peers for feedback.

6.3 Limitations of Study

The study’s findings are limited to the students who participated in the study and data collection tools used and when it was feasible to deploy the tools.

Throughout this research study, I made decisions about what to do and when, what data to collect and what lens to bring to my analyses. Hence my study's findings are influenced by my own beliefs, but I endeavoured to make my account of the student experiences as unbiased as possible. In this study's interviews, students were invited to participate. This approach may have introduced a selection bias due to the possibility that students who initially volunteered may have been interested in the topic of the study, and thus these participants may have different characteristics than the overall study sample.

6.4 Implications

6.4.1 Implications for Theory

Other studies have shown that students can transform some aspects of epistemologies while others remain persistent (Schommer, 1993a). A surprising feature of this study was how quickly a transformation occurred and remained transformed in some aspects of epistemology while another aspect of epistemology did not change at all. This suggests that some factors can be described as epistemological resources, as put forth by Hammer and Elby (2002), where the factors are more contextual and susceptible to change. Other aspects of epistemology are more permanent, as described by developmental (Baxter Magolda, 1992; King & Kitchener, 1994; Perry, 1970) and dimensional models (Hofer & Pintrich, 1997; Schommer, 1993a). This is the first study, to my knowledge, to suggest that multiple models of epistemology are needed to fully describe epistemological transformations.

6.4.2 Implications for Practice

The study's findings have implications on how future Vantage College programs might be redesigned to take into account the influence of pedagogy on students' prior epistemologies of science. Literature has suggested specific pedagogies to promote epistemological growth (Baxter Magolda, 1992; Felder & Brent, 2004b; Hammer & Elby, 2003; Herron & Nurrenbern, 1999; Hofer, 2004b; Hogan & Maglienti, 2001; Schraw, 2001), but this study provides evidence of a clear link to the importance of pedagogy in the transformation of epistemologies towards more canonical perspectives in a relatively short time period. Literature has shown epistemological transformations occur over a four-year degree or longer (Baxter Magolda, 1992; Perry, 1970) or when students engage in research (Samarapungavan et al., 2006). Supported by qualitative and quantitative evidences, there is a link between peer learning pedagogy and the transformation of student epistemology that peers are a source of knowledge. There is a link between guided-inquiry based laboratories and the change in student views of self-learning. More canonical epistemologies were found to be related to positive study approaches, problem-solving strategies, and academic performance. To best help our international students and other first-year students, there should be a focus on a consistent active learning pedagogy used in multiple first-year courses. The Vantage One Science students did not exhibit challenges or difficulty to peer-learning pedagogy to the same extent as what has been reported in the literature (Andrade, 2006). Because multiple courses in the Vantage One Science Program employ peer learning, students are repeatedly receiving the similar messages with respect to peer learning from various instructors, likely contributing to their views on the value of peer learning.

The suggestion to focus on a consistent active learning pedagogy in multiple courses can come to fruition through a teacher education program. Teachers in training should become aware of the importance of epistemological growth and understand the importance of active learning pedagogies to promote canonical epistemologies.

6.4.3 Implications for Research

Future research should involve a longitudinal study to explore how the canonically oriented epistemologies are sustained throughout a four-year science degree program. In this study, epistemological transformations occurred a relatively short time period likely due to the uniqueness of the Vantage One Science Program. Research is needed to examine how student epistemologies are affected when students are enrolled in second-year university when they do not belong to a cohort and experience inconsistent pedagogies among their courses.

This study hopes to inspire more mixed methods approaches to epistemology. Although there is a trend in the field for assessing epistemology using surveys (Hofer, 2004a), this study highlights the importance of pairing survey data with interviews and other qualitative methods. Much current epistemological research still relies on interviewing (Baxter Magolda, 2006; Hofer, 2004a), but both qualitative and quantitative data together provided a richness and depth to the analysis.

6.5 Conclusions

Some aspects of student epistemologies transformed over the course of the first year Vantage program while others did not change. When aspects of epistemologies did transform, they evolved towards a more canonical epistemology. Transformations included viewing science as more than a classroom endeavour, viewing oneself and peers as sources of knowledge and becoming more aware of the nature of science (e.g., its development, uncertainty and evolving nature). Some of these transformations can be linked to the pedagogy experienced by students in the Vantage One Science Program. Specifically, the use of peer-based pedagogy in multiple courses and inquiry-based learning in the chemistry laboratories influenced change in student epistemologies. Qualitative and quantitative data suggest that components of student learning, including exam performance, study strategies, and problem-solving behaviour were positively influenced by more canonical epistemological dispositions. These themes appear to be related. The program influenced epistemology which then, influenced student learning. Although the focus of this study was not an assessment of the Vantage program, there are indications from both the quantitative and qualitative analysis that both coursework and pedagogy used in the program influenced epistemological transformations. The findings of this study are consistent with literature recommendations for classroom environments that enhance epistemological development. The recommendations include: encouraging learner questions and comments which maps well with inquiry-based learning used in the CHEM 121/123 laboratory; instructor recognition of learner reactions, and increased emphasis on learner participation, which maps onto peer-learning pedagogy (Baxter Magolda, 1992; Felder & Brent, 2004); and an explicit approach when teaching about the nature of science (Abd-El-Khalick & Lederman, 2000) which maps well with the courses required by the Vantage One Science Program.

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Appendices

Appendix A : Additional Details of Study Methods (Chapter 3)

	Classroom Activity	% of Final Grade
Common to all sections of CHEM 121	Midterm Exams (2)	20
	Final Exam	50
	Laboratory	20
Specific only to Vantage Sections	In-Class Tests (2)	6
	Homework and online quizzes	3
	In-class Participation (worksheets + clickers)	1

Table A-1: Mark Breakdown in CHEM 121 Vantage 2015W

	Classroom Activity	% of Final Grade
Common to all sections of CHEM 123	Midterm Exam (1)	20
	Final Exam	50
	Laboratory	20
Specific only to Vantage Sections	Quizzes and Homework	4
	Review online tests	4
	In-class Participation (clickers)	1
	Survey	1

Table A-2: Mark Breakdown for CHEM 123 Vantage 2016S

Date
Thank you for participating in this important study.
This survey DOES NOT COUNT TOWARDS YOUR GRADE. Your participation is entirely VOLUNTARY and **your responses will be kept PRIVATE**. Your other course instructors will NOT have access to your responses so feel free to answer HONESTLY.
If you do not understand a question due to language, please ask.
Please see the consent form at the end of this package with more details.

Name:

Student Number:

EPISTEMOLOGICAL BELEIFS ASSESSMENT FOR THE PHYSICAL SCIENCES (White, B., Elby, A., Frederiksen, J., & Schwartz, C., 1999)

Part 1: DIRECTIONS: For each of the following items, please read the statement, and indicate using the appropriate letter the answer that describes how strongly you agree or disagree.

1. Tamara just read something in her science textbook that seems to disagree with her own experiences. But to learn science well, Tamara shouldn't think about her own experiences; she should just focus on what the book says.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

2. When it comes to understanding physics or chemistry, remembering facts isn't very important.

A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

3.Obviously, computer simulations can predict the behavior of physical objects like comets. But simulations can also help scientists estimate things involving the behavior of *people*, such as how many people will buy new television sets next year.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

4. When it comes to science, most students either learn things quickly, or not at all.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

5. If someone is having trouble in physics or chemistry class, studying in a better way can make a big difference.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

6. When it comes to controversial topics such as which foods cause cancer, there's no way for scientists to evaluate which scientific studies are the best. Everything's up in the air!
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

7. A teacher once said, "I don't *really* understand something until I teach it." But actually, teaching doesn't help a teacher understand the material better; it just reminds her of how much he or she already knows.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

8. Scientists should spend almost all their time gathering information. Worrying about theories can't really help us understand anything.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

9. Someone who doesn't have high natural ability can still learn the material well even in a hard chemistry or physics class.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

10. Often, a scientific principle or theory just doesn't make sense. In those cases, you have to accept it and move on, because not everything in science is supposed to make sense.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

11. When handing in a physics or chemistry test, you can generally have a sense of well you did even before talking about it with other students.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

12. When learning science, people can understand the material better if they relate it to their own ideas.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

13. If physics and chemistry teachers gave *really clear* lectures, with plenty of real-life examples and sample problems, then most good students could learn those subjects without doing lots of sample questions and practice problems on their own.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

14. Understanding science is really important for people who design rockets, but not important for politicians.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

15. When solving problems, the key thing is knowing the methods for addressing each particular type of question. Understanding the "big ideas" might be helpful for specially-written problems, but not for most regular problems.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

16. Given enough time, almost everybody could learn to think more scientifically, if they really wanted to.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

17. To understand chemistry and physics, the formulas (equations) are really the main thing; the other material is mostly to help you decide which equations to use in which situations.
A: Strongly disagree **B:** Somewhat disagree **C:** Neutral **D:** Somewhat agree **E:** Strongly agree

Part 2: DIRECTIONS*:* Multiple choice. Circle the answer that best fits your view.

18. If someone is trying to learn physics, is the following a good kind of question to think about? Two students want to break a rope. Is it better for them to (1) grab opposite ends of the rope and pull (like in tug-of-war), or (2) tie one end of the rope to a

wall and both pull on the other end together?
(a) *Yes, definitely*. It's one of the best kinds of questions to study.
(b) *Yes, to some extent*. But other kinds of questions are equally good.
(c) *Yes, a little*. This kind of question is helpful, but other kinds of questions are more helpful.
(d) *Not really*. This kind of question isn't that great for learning the main ideas.
(e) *No, definitely not*. This kind of question isn't helpful at all.

19. Scientists are having trouble predicting and explaining the behavior of thunder storms. This could be because thunder storms behave according to a very complicated or hard-to-apply set of rules. Or, that could be because some thunder storms don't behave consistently according to *any* set of rules, no matter how complicated and complete that set of rules is. In general, why do scientists sometimes have trouble explaining things? Please read all options before choosing one.
(a) Although things behave in accordance with rules, those rules are often complicated, hard to apply, or not fully known.
(b) Some things just don't behave according to a consistent set of rules.
(c) Usually it's because the rules are complicated, hard to apply, or unknown; but sometimes it's because the thing doesn't follow rules.
(d) About half the time, it's because the rules are complicated, hard to apply, or unknown; and half the time, it's because the thing doesn't follow rules.
(e) Usually it's because the thing doesn't follow rules; but sometimes it's because the rules are complicated, hard to apply, or unknown.

20. In chemistry, how do the most important formulas relate to the most important concepts? Please read all choices before picking one.
(a) The major formulas summarize the main concepts; they're not really separate from the concepts. In addition, those formulas are helpful for solving problems.
(b) The major formulas are kind of "separate" from the main concepts, since concepts are *ideas*, not equations. Formulas are better characterized as problem-solving tools, without much conceptual meaning.
(c) Mostly (a), but a little (b).
(d) About half (a) and half (b).
(e) Mostly (b), but a little (a).

21. To be successful at *most things in life*...
(a) Hard work is much more important than inborn natural ability.
(b) Hard work is a little more important than natural ability.
(c) Natural ability and hard work are equally important.
(d) Natural ability is a little more important than hard work.
(e) Natural ability is much more important than hard work.

22. To be successful at *science*...
(a) Hard work is much more important than inborn natural ability.
(b) Hard work is a little more important than natural ability.
(c) Natural ability and hard work are equally important.
(d) Natural ability is a little more important than hard work.
(e) Natural ability is much more important than hard work.

23. Of the following test formats, which is best for measuring how well students understand the material in chemistry? Please read each choice before picking one.
(a) A large collection of short-answer or multiple choice questions, each of which covers one specific fact or concept.
(b) A small number of longer questions and problems, each of which covers several facts and concepts.
(c) Compromise between (a) and (b), but leaning more towards (a).
(d) Compromise between (a) and (b), favoring both equally.
(e) Compromise between (a) and (b), but leaning more towards (b).

Part 3 DIRECTIONS*:* In each of the following items, you will read a short discussion between two students who disagree about some issue. Then you'll indicate whether you agree with one student or the other.

24.
Brandon: A good science textbook should show how the material in one chapter relates to the material in other chapters. It shouldn't treat each topic as a separate "unit," because they're not really separate.
Jamal: But most of the time, each chapter is about a different topic, and those different topics don't always have much to do with each other. The textbook should keep everything separate, instead of blending it all together.

With whom do you agree? Read all the choices before circling one.
(a) I agree almost entirely with Brandon.
(b) Although I agree more with Brandon, I think Jamal makes some good points.
(c) I agree (or disagree) equally with Jamal and Brandon.
(d) Although I agree more with Jamal, I think Brandon makes some good points.
(e) I agree almost entirely with Jamal.

25.
Anna: I just read about Kay Kinoshita, the physicist. She sounds naturally brilliant.
Emily: Maybe she is. But when it comes to being good at science, hard work is more important than "natural ability." I bet Dr. Kinoshita does well because she has worked really hard.
Anna: Well, maybe she did. But let's face it, some people are just smarter at science than other people. Without natural ability, hard work won't get you anywhere in science!
(a) I agree almost entirely with Anna.
(b) Although I agree more with Anna, I think Emily makes some good points.
(c) I agree (or disagree) equally with Anna and Emily.
(d) Although I agree more with Emily, I think Anna makes some good points.
(e) I agree almost entirely with Emily.

26.
Justin: When I'm learning science concepts for a test, I like to put things in my own words, so that they make sense to me.
Dave: But putting things in your own words doesn't help you learn. The textbook was written by people who know science really well. You should learn things the way the textbook presents them.
(a) I agree almost entirely with Justin.
(b) Although I agree more with Justin, I think Dave makes some good points.
(c) I agree (or disagree) equally with Justin and Dave.
(d) Although I agree more with Dave, I think Justin makes some good points.
(e) I agree almost entirely with Dave.

27.
Julia: I like the way science explains how things I see in the real world.
Carla: I know that's what we're "supposed" to think, and it's true for many things. But let's face it, the science that explains things we do in lab at school can't really explain earthquakes, for instance. Scientific laws work well in some situations but not in most situations.
Julia: I still think science applies to almost all real-world experiences. If we can't figure out how, it's because the stuff is very complicated, or because we don't know enough science yet.
(a) I agree almost entirely with Julia.
(b) I agree more with Julia, but I think Carla makes some good points.
(c) I agree (or disagree) equally with Carla and Julia.
(d) I agree more with Carla, but I think Julia makes some good points.
(e) I agree almost entirely with Carla.

28.
Leticia: Some scientists think the dinosaurs died out because of volcanic eruptions, and others think they died out because an asteroid hit the Earth. Why can't the scientists agree?
Nisha: Maybe the evidence supports both theories. There's often more than one way to interpret the facts. So we have to figure out what the facts mean.
Leticia: I'm not so sure. In stuff like personal relationships or poetry, things can be ambiguous. But in science, the facts should speak for themselves.
(a) I agree almost entirely with Leticia.
(b) I agree more with Leticia, but I think Nisha makes some good points.
(c) I agree (or disagree) equally with Nisha and Leticia.
(d) I agree more with Nisha, but I think Leticia makes some good points.
(e) I agree almost entirely with Nisha.

29.
Jose: In my opinion, science is a little like fashion; something that's "in" one year can be "out" the next. Scientists regularly change their theories back and forth.
Miguel: I have a different opinion. Once experiments have been done and a theory has been made to explain those

experiments, the matter is pretty much settled.
There's little room for argument.
(a) I agree almost entirely with Jose.
(b) Although I agree more with Jose, I think Miguel makes some good points.
(c) I agree (or disagree) equally with Miguel and Jose.
(d) Although I agree more with Miguel, I think Jose makes some good points.
(e) I agree almost entirely with Miguel.

30.
Jessica and Mia are working on a chemistry homework assignment together...
Jessica: O.K., we just got problem #1. I think we should go on to problem #2.
Mia: No, wait. I think we should try to figure out why the thing takes so long to reach the ground.
Jessica: Mia, we know it's the right answer from the back of the book, so what are you worried about? If we didn't understand it, we wouldn't have gotten the right answer.
Mia: No, I think it's possible to get the right answer without really understanding what it means.
(a) I agree almost entirely with Jessica.
(b) I agree more with Jessica, but I think Mia makes some good points.
(c) I agree (or disagree) equally with Mia and Jessica.
(d) I agree more with Mia, but I think Jessica makes some good points.
(e) I agree almost entirely with Mia.

END OF SURVEY. THANK YOU!

Table A-3: EBAPS Survey Items

Consent Form to Participate in Personal Epistemology and Student Experiences of the Interactive Teaching in Chemistry

Who is conducting the study?
Principal Investigator: Dr. Samson Nashon**,** Department of Curriculum and Pedagogy, samson.nashon@ubc.ca/604-822-5315.
Co-Investigators: Dr. Marina Milner-Bolotin, Department of Curriculum and Pedagogy, marina.milner-bolotin@ubc.ca/604-822-4234. Dr. Douglas Adler, Department of Curriculum and Pedagogy, douglas.adler@ubc.ca /604-822-5328**.** Anka Lekhi, Department of Curriculum and Pedagogy and Department of Chemistry, anka@chem.ubc.ca/ 604-827-3492.

Why are we doing this study?
The purpose of this project is to study how epistemologically and culturally diverse students experience a teaching environment where interactive pedagogy is employed.
UBC undergraduate students enrolled in Vantage sections of Chemistry 121 and 123 are invited to participate in a study aimed at improving the learning experience in first year Chemistry and other science classes. Participation is voluntary. Participation will not affect your grades or class standing. This study is conducted by the department of Curriculum and Pedagogy and the Chemistry department. Conclusions may be published in some form and/or presented publicly, but without any information that could be used to identify the participants.

How is the study done?
Your participation will involve completing a survey. The survey is aimed to help us better understand how you views on knowledge. The researcher may also look at your Chemistry 121 and 123 grades and any formal assessments, including exams, quizzes and reports for epistemological indicators.

How will your privacy be maintained?
Your confidentiality will be respected. Original data collected in this study will be examined by the research team members only after the completion of Chemistry 121. No one other than Anka Lekhi will have access to your identity. Any written or printed out materials with identifiable information will be stored in a locked filing cabinet and will not be available to any of your current instructors. Any information in electronic format will be stored on password protected and encrypted computers. No individual student identifiers will be used in any published or publicly presented work.

What happens next?
The outcomes of this study will be used to inform a continual improvement process around pedagogy for teaching at UBC Vancouver and may be published in peer reviewed journals without any identifiers.

Is there any way being in this study could pose a risk for you?
There are no anticipated risks for research participants. However, some of the questions you will be asked may seem personal. You do not have to answer any question if you do not want to and you can opt out at any time during the survey with no repercussions.

What are the benefits of participating in this study?
The benefits to you are indirect; the data collected are part of a major UBC initiative to improve education. The data from the survey is an essential component in understanding what changes in educational approaches are working well and where further improvements are needed. This may result in improvements to science courses you take in future semesters.
The benefits to society in general will be improved science education that most students will find more interesting and relevant to their lives.

Who can you contact if you have questions about the study?
If you have any questions or concerns about what we are asking of you, please contact the principal investigator or one of the co-investigators. Their names, email addresses, and telephone numbers are listed at the top of the first page of this form.

Who can you contact if you have complaints or concerns about the study?
If you have any concerns about your rights as a research subject and/or your experiences while participating in this study, 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 RSIL@ors.ubc.ca or call toll free 1-877-822-8598.
Taking part in this survey is entirely voluntary. You have the right to refuse to participate in this survey. If you decide to take part, you may choose to pull out of the survey at any time without giving a reason and without jeopardizing your class standing.
*If you require additional time to review this consent form, please feel free to do so.

By handing in a completed survey, you are indicating that you have read the consent form and that you consent to participate in this study.

Table A-4: Consent Form for Survey and Access to Student Grades.

		16-May	EXAMPLE			16-May			
Activity		Minutes:	Comments:	Individual (1) or with other students? Specify number of students in your group.	Location:	Minutes	Comments	Individual (1) or with other students? Specify number of students in your group.	Location
I read the online textbook chapter for the first time	*Before Class*	20		1	On the bus				
	After Class								
I re-read sections of the online textbook chapter	*Before Class*								
	After Class	10		1	library				
I made my own notes outside of class	*Before Class*								
	After Class								
I reviewed my own notes or my instructor's outside of class	*Before Class*								
	After Class								
I watched online videos posted by	*Before Class*								
	After Class								
I tried the problem set questions before looking at the answer key	*Before Class*								
	After Class	40	Me and two of my friends did the problem	3	At the UBC library				
I tried the problem set questions with the answer key	*Before Class*								
	After Class								
I tried the questions on the Chem 123 practice exams	*Before Class*								
	After Class								
I tried questions posted by my instructor such as homework assignments or	*Before Class*								
	After Class								
I tried questions from resources outside Chem 123 such as other first-year textbooks and online materials. PLEASE PROVIDE DETAILS	*Before Class*								
	After Class	20	I google'd questions on reversible processes and tried those.	1	At home				
I used the Piazza discussion board to post questions or read other students questions	*Before Class*								
	After Class								
I visited my Instructor's office hours to ask questions	*Before Class*								
	After Class								
I met with a tutor	*Before Class*								
	After Class								
I used social media such as Facebook or Twitter to post questions or read other students questions or answer questions	*Before Class*								
	After Class								
I used a peer tutoring service such as AMS tutoring or Prep 101	*Before Class*								
	After Class								
I used materials other than practice questions outside of Chem 123 such as online videos, wikipedia and/or other textbooks	*Before Class*								
	After Class	30	Me and two other friends used wikipedia to help us with definitions.	3	At the UBC library				
Other (Please specify)	*Before Class*								
	After Class								
"Before Class" refers to topic being discussed before class and "After Class" refers to after the topic is discussed in class									

Figure A-1: Study Log Checklist

Focus Group I Questions in January 2016
1. Imagine an alien came in contact with you and says, I want to learn science. What advice would you give the alien? What does learning science involve? How do you learn Chemistry, for example? 2. Do you think ANYONE can learn chemistry or only a few people? 3. What kind of thinking is required in science, especially in chemistry? 4. Do you consider the CHEM 121 course materials as reliable? Please give arguments for your answer. 5. How is chemistry knowledge created? 6. If we would wipe out all knowledge on planet, in 50 year, would the Chemistry book be the same? 7. Does chemistry knowledge ever change? If so, when? 8. What makes scientific knowledge different from other types of knowledge? 9. Is scientific knowledge better described as uncovering or discovering or creating? 10. A scientist will predict one thing for climate change and a different scientist predicts differently. Why? 11. Compare last semester to your previous school, what was different?

Table A-5 :Questions Prepared for the First Focus Group Interviews

Focus Group II Questions: May 2016
1. When you compare back to starting first year in September and your expectations of the knowledge you would gain, are you disappointed at anything? Surprised? 2. How did the Chem lab meet your expectations? 3. How does CHEM 123 compare with other courses you have taken? Lecture and lab? 4. One of the results from the survey is that more students find physics and chemistry knowledge as coherent, conceptual, highly-structured, unified whole instead of a bunch of weakly connected pieces without much structure and consisting mainly of facts and formulas. Would you agree? Why do you think that is? Can you think of situations in a classroom that specifically made you think of science that way? Can you think of classroom activities that are designed to get you to think of science that way? 5. Another result from the survey is that LESS students find that learning science is about constructing one's own understanding by working through the material actively, by relating new material to prior experiences, intuitions, and knowledge, and by reflecting upon and monitoring one's understanding and it is more about absorbing information. Would you agree? Why do you think that is? Can you think of situations in a classroom that specifically made you think of science that way? 6. Another result is that less students see science as applicable to real life. Why do you think that is? Would you agree? Why do you think that is? Can you think of situations in a classroom that specifically made you think of science that way? 7. More students do not think that science is absolute/ set in stone. Why do you think that is? 8. This stayed about the same: Student beliefs about being good at science mostly a matter of fixed natural ability? 9. Has your opinion changed since September?

Table A-6: Questions Prepared for Second Focus Group Interviews

Interview Questions: Interview I	Potential Probing Q
1. How would you describe the role of the instructor and student in your previous school? How does that compare to the role of your Chemistry instructor NOW? 2. If you were to go back and talk to yourself before you came to UBC. What advice would you give yourself to help you transition into university? I noticed that you did not specify…. (peer learning or lab or …) why not? 3. There is a significant amount of peer-learning activities (activities where you are asked to work with a partner) in your Chemistry class. What is the intention of the instructor with these activities? I noticed that students are more engaged during peer learning than in CHEM 121. Why do you think that is? Do you study with your peers on your own? Why or why not? 4. What is truth to you? You are learning about Gibbs Free Energy. Is this 'truth'? 5. What was one new thing you learned in C121? How do you learn it? 6. What is your opinion on the following: When solving problems, the key thing is knowing the methods for addressing each particular type of question. Understanding the "big ideas" might be helpful for specially-written problems, but not for most regular problems. 7. In what ways is chemistry similar to poetry? 8. Is it important to see the instructor go through a problem even when you know the right answer? 9. What is more important- hard work or innate ability? 10. Explain the change in your answers to the following survey questions questions (VARIED PER PARTICIPANT):	Can you tell me more about that? What do you mean by….? Can you give me an example of what you mean? Here you said… then you said… can you help me connect the two?

Table A-7: Questions Prepared for First Semi-structured Interview

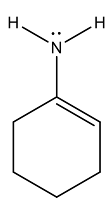
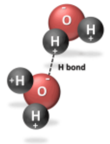
Interview Questions: Interview II	Potential Probing Q
1. What did you think science was before? What do you think science now is? If there is a difference, what influenced the change? 2. What was the most stressful classroom situation you had this year? 3. What was a situation in the classroom where you overcame a challenge or felt proud of yourself? 4. Have scientists seen an atom? How do we have such an elaborate structure? 5. In what way do creativity and imagination have a place in science? 6. On the last day of the CHEM labs, you were asked to present your Vitamin C poster. What do you think was the purpose of that activity? 7. What is the most effective way to learn science? 8. What kind of test questions or assignments effectively measures your understanding of science? 9. What do you think is most important- learning science content or learning how science has been developed? Is it more important to learn the effect of science or how society has effected science? 10. What do you think when you encounter a situation where you hear two different explanations for the same idea in science? 11. I noticed that in your study log that you mainly study alone (ask if applicable). Why? 12. In CHEM 123, you learned that the N in the following molecule is sp^2 hybridized. This is different from the rules you saw in CHEM 121. When you encounter an inconsistency like this, what do you think?  The N is sp^2 hybridized in this structure. Task—Questionnaire 1. What questions did you find interesting? 2. Explain your answers to the following questions (VARIED PER PARTICIPANT)	Can you tell me more about that? What do you mean by….? Can you give me an example of what you mean? Here you said… then you said… can you help me connect the two?

Table A-8: Questions Prepared for Second Semi-structured Interview

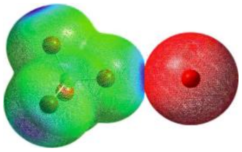
Task-based Interview I

Case Study: Halogen-bonding

You may remember learning about Hydrogen bonding in CHEM 121. Hydrogen bonding is an intermolecular attractive force between a Hydrogen, that is bonded to F, N, or O, on one molecule, being attracted to a F, N, or O of a neighboring molecule. Water has H-bonding.



Halogen bonding is another attractive intermolecular interaction that is similar to H-bonding. An example of halogen bonding would be the attractive interaction between Br in CBr_4 and a neighboring Br^- ion:



Halogen bonding is important in biological systems and has potential for drug design.

The nature of the interaction in halogen bonding has been described in multiple ways. One group of chemists describe the interaction as electrostatic (oppositely charged species are attracted together). And a different group of chemists describe the interaction as one group donates and shares electrons with the other group (covalent).

Electrostatic Description:

From: Rosokha, S. V., Stern, C. L., & Ritzert, J. T. (2013). Experimental and Computational Probes of the Nature of Halogen Bonding: Complexes of Bromine-Containing Molecules with Bromide Anions. *Chemistry–A European Journal*, *19*(27), 8774-8788.

Page 8774:

"…halogen bonding is related to the electrostatic attraction between a covalently-bonded halogen and an electron-rich species."

Electron donation (Covalent) Description:

From: Metrangolo, P., Meyer, F., Pilati, T., Resnati, G., & Terraneo, G. (2008). Halogen bonding in supramolecular chemistry. *Angewandte Chemie International Edition*, *47*(33), 6114-6127.

Page 6116:

"Consistent with the rationalization of halogen bonding as being an electron donation…"

Does it surprise you that there are two different descriptions? Why or why not?

How would you decide which is more accurate?

Chemistry Problems

1. The ΔG° of acetic acid reacting with water at room temperature is +27.07kJ:

$$CH_3COOH \;+\; H_2O \;\rightarrow\; CH_3COO^- \;+\; H_3O^+$$

If 0.1M acetic acid is added to water at room temperature, will it react with water? Does the pH of the water stay the same, increase or decrease? What side (products or reactants) is favored at equilibrium?

2. The very unstable fulminate ion (CNO^-) has the N atom in the centre. Provide a rationale as to why this ion is so unstable. What bond is most likely to break in this ion?

3. The following images are of the same set of 5 vials taken under a UV lamp and then again in under ambient light. Why are the vials different colors in each image?

Table A-9: Task-based Interview Questions I

Task-based interview questions II

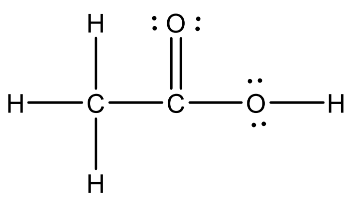
1. The K_b of hydrazine ($H_2N\text{-}NH_2$) at 298 K is 9.8×10^{-7}. Consider the following reaction between hydrazine and water:

$$H_2N\text{-}NH_2 + H_2O \rightleftharpoons H_2N\text{-}NH_3^{+} + OH^{-}$$

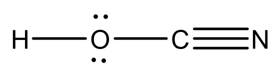
Which species is weaker of the two acids?

2. HCl and HI are both strong acids. If HCl is added to water, the pH would be acidic. If an equal amount of HI is added to water, the pH would also be acidic but there would be a slight difference in pH between the two solutions. Which solution would be MORE acidic?

3. Consider the structures and the pKa's of the following two acids at 298 K:



pKa = 5



pKa = 3

(a) Draw an acid/base reaction that occurs between the stronger acid of the two species and conjugate base of the other species. Use curved arrows to show how the bonds will form and break.

(b) How can you determine the equilibrium constant for the reaction you have drawn in part (a)? At standard state, would reaction (a) be spontaneous at 298 K?

Table A-10: Task-based Interview Questions II

Consent Form to Participate in Personal Epistemology and Culturally Diverse Student Experiences of Chemistry 123

Who is conducting the study?
Principal Investigator: Dr. Samson Nashon, Department of Curriculum and Pedagogy, samson.nashon@ubc.ca/604-822-5315.
Co-Investigators: Dr. Marina Milner-Bolotin, Department of Curriculum and Pedagogy, marina.milner-bolotin@ubc.ca/604-822-4234. Dr. Douglas Adler, Department of Curriculum and Pedagogy, douglas.adler@ubc.ca /604-822-5328. Anka Lekhi, Department of Curriculum and Pedagogy and Department of Chemistry, anka@chem.ubc.ca/ 604-827-3492.

Why are we doing this study?
The purpose of this project is to study how epistemologically and culturally diverse students experience a teaching environment where Flipped Classroom pedagogy is employed.

UBC undergraduate students enrolled in Vantage sections of Chemistry 123 are invited to participate in a study aimed at improving the learning experience in first year Chemistry and other science classes. Participation is voluntary. Participation will not affect your grades or class standing. This study is conducted by the department of Curriculum and Pedagogy and the Chemistry department at UBC. Conclusions may be published in some form and/or presented publicly, but without any information that could be used to identify the participants.

How is the study done?
Your participation will involve being interviewed. The interview include questions and answers aimed at helping us understand your perceptions and experiences of the activities in your first-year chemistry class and compare those to previous classroom experiences you have had. This interview may be done individually or in groups. The interviews will be held in the Chemistry building. With your permission, the interview will be audio-recorded and may be video-taped; this recording will help us create a more accurate transcript of the interview. You will have access to a copy of the transcript and have the opportunity to correct anything you wish. Only the researchers will have access to the audio/video-recordings, and these will be securely stored at all times. The researcher will also look at your Chemistry 121 and 123 grades and any formal assessments, including exams, quizzes and reports for epistemological indicators.

What happens next?
The outcomes of this study will be used to inform a continual improvement process around pedagogy for teaching at UBC Vancouver and may be published in peer reviewed journals without any identifiers. You will be contacted individually for permission to use passages or quotes you may provide during the research process.

Is there any way being in this study could pose a risk for you?
There are no anticipated risks for research participants. However, some of the questions you will be asked may seem personal. You do not have to answer any question if you do not want to and you can opt out at any time during the study with no repercussions.

What are the benefits of participating in this study?
The benefits to you are indirect; the data collected are part of a major UBC initiative to improve education. The data from the interviews is an essential component in understanding what changes in educational approaches are working well and where further improvements are needed. This may result in improvements to science courses you take in future semesters.

The benefits to society in general will be improved science education that most students will find more interesting and relevant to their lives.

What are the incentives to participate in this study?
For your participation, you will receive free pizza.

How will your privacy be maintained?
Your confidentiality will be respected. Original data collected in this study will be examined by the research team members only. You will have a choice either to be identified by name in the transcript of your interview or to have your identity kept more private through the use of a pseudonym. You can change your mind about how to be identified at any point in the study. No one other than Anka Lekhi will have access to your identity. Any written or printed out materials with identifiable information will be stored in a locked filing cabinet and will not be available to any of your current instructors. Any information in electronic format will be stored on password protected and encrypted computers. No individual student

identifiers will be used in any published or publicly presented work.

Who can you contact if you have questions about the study?
If you have any questions or concerns about what we are asking of you, please contact the principal investigator or one of the co-investigators. Their names, email addresses, and telephone numbers are listed at the top of the first page of this form.

Who can you contact if you have complaints or concerns about the study?
If you have any concerns about your rights as a research subject and/or your experiences while participating in this study, 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 RSIL@ors.ubc.ca or call toll free 1-877-822-8598.

Taking part in this study is entirely voluntary. You have the right to refuse to participate in this study. If you decide to take part, you may choose to pull out of the study at any time without giving a reason and without jeopardizing your class standing. *If you require additional time to review this consent form, please feel free to do so and return the signed form to Anka Lekhi by tomorrow.

Your signature below indicates that you have received a copy of this consent form for your own records. Your signature below indicates that you consent to participate in this study.

____
Participant Signature Date

____
Printed Name of the Participant signing above

Table A-11: Consent Form for Focus Group Interviews

Consent Form to Participate in Personal Epistemology and Culturally Diverse Student Experiences of the Flipped Classroom in Chemistry 123

Who is conducting the study?

Principal Investigator: Dr. Samson Nashon**,** Department of Curriculum and Pedagogy, samson.nashon@ubc.ca/604-822-5315.

Co-Investigators: Dr. Marina Milner-Bolotin, Department of Curriculum and Pedagogy, marina.milner-bolotin@ubc.ca/604-822-4234. Anka Lekhi, Department of Curriculum and Pedagogy and Department of Chemistry, anka@chem.ubc.ca/ 604-827-3492.

Why are we doing this study?

The purpose of this project is to study how epistemologically and culturally diverse students experience a teaching environment where Flipped Classroom pedagogy is employed.

UBC undergraduate students enrolled in Vantage sections of Chemistry 123 are invited to participate in a study aimed at improving the learning experience in first year Chemistry and other science classes. Participation is voluntary. Participation will not affect your grades or class standing. This study is conducted by the department of Curriculum and Pedagogy, the Chemistry department, and the Flexible Learning Initiative at UBC. Conclusions may be published in some form and/or presented publicly, but without any information that could be used to identify the participants.

How is the study done?

Your participation will involve being interviewed, keeping a study journal and a researcher will observe your Chemistry 123 course. These activities will be spread over the next 7 months. There will be two types of interviews. The first type of interview include questions and answers aimed at helping us understand your perceptions and experiences of the activities in your first-year chemistry class and compare those to previous classroom experiences you have had. The second type of interview involves solving chemistry problems aloud to help us better understand how you view knowledge. The interviews will be held in the Chemistry building. With your permission, the interview will be audio-recorded and may be video-taped; this recording will help us create a more accurate transcript of the interview. You will have access to a copy of the transcript and have the opportunity to correct anything you wish. Only the researchers will have access to the audio/video-recordings, and these will be securely stored at all times. The researcher will also look at your Chemistry 121 and 123 grades and any formal assessments, including exams, quizzes and reports for epistemological indicators.

What happens next?

The outcomes of this study will be used to inform a continual improvement process around pedagogy for teaching at UBC Vancouver and may be published in peer reviewed journals without any identifiers. You will be contacted individually for permission to use passages or quotes you may provide during the research process.

Is there any way being in this study could pose a risk for you?

There are no anticipated risks for research participants. However, some of the questions you will be asked may seem personal. You do not have to answer any question if you do not want to and you can opt out at any time during the study with no repercussions.

What are the benefits of participating in this study?

The benefits to you are indirect; the data collected are part of a major UBC initiative to improve education. The data from the interviews is an essential component in understanding what changes in educational approaches are working well and where further improvements are needed. This may result in improvements to science courses you take in future semesters.

The benefits to society in general will be improved science education that most students will find more interesting and relevant to their lives.

What are the incentives to participate in this study?

For your participation, you will receive a $10 gift card to UBC Bookstore.

How will your privacy be maintained?

Your confidentiality will be respected. Original data collected in this study will be examined by the research team members only. You will have a choice either to be identified by name in the transcript of your interview or to have your identity kept more private through the use of a pseudonym. You can change your mind about how to be identified at any point in the study. No one other than Anka Lekhi will have access to your identity. Any written or printed out materials with identifiable information will be stored in a locked filing cabinet and will not be available to any of your current instructors. Any information in electronic format will be stored on password protected and encrypted computers. No individual student identifiers will be used in any published or publicly presented work.

Who can you contact if you have questions about the study?

If you have any questions or concerns about what we are asking of you, please contact the principal investigator or one of the co-investigators. Their names, email addresses, and telephone numbers are listed at the top of the first page of this form.

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Taking part in this study is entirely voluntary. You have the right to refuse to participate in this study. If you decide to take part, you may choose to pull out of the study at any time without giving a reason and without jeopardizing your class standing or your $10 gift card.

*If you require additional time to review this consent form, please feel free to do so and return the signed form to Anka Lekhi by tomorrow.

Your signature below indicates that you have received a copy of this consent form for your own records. Your signature below indicates that you consent to participate in this study.

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Participant Signature Date

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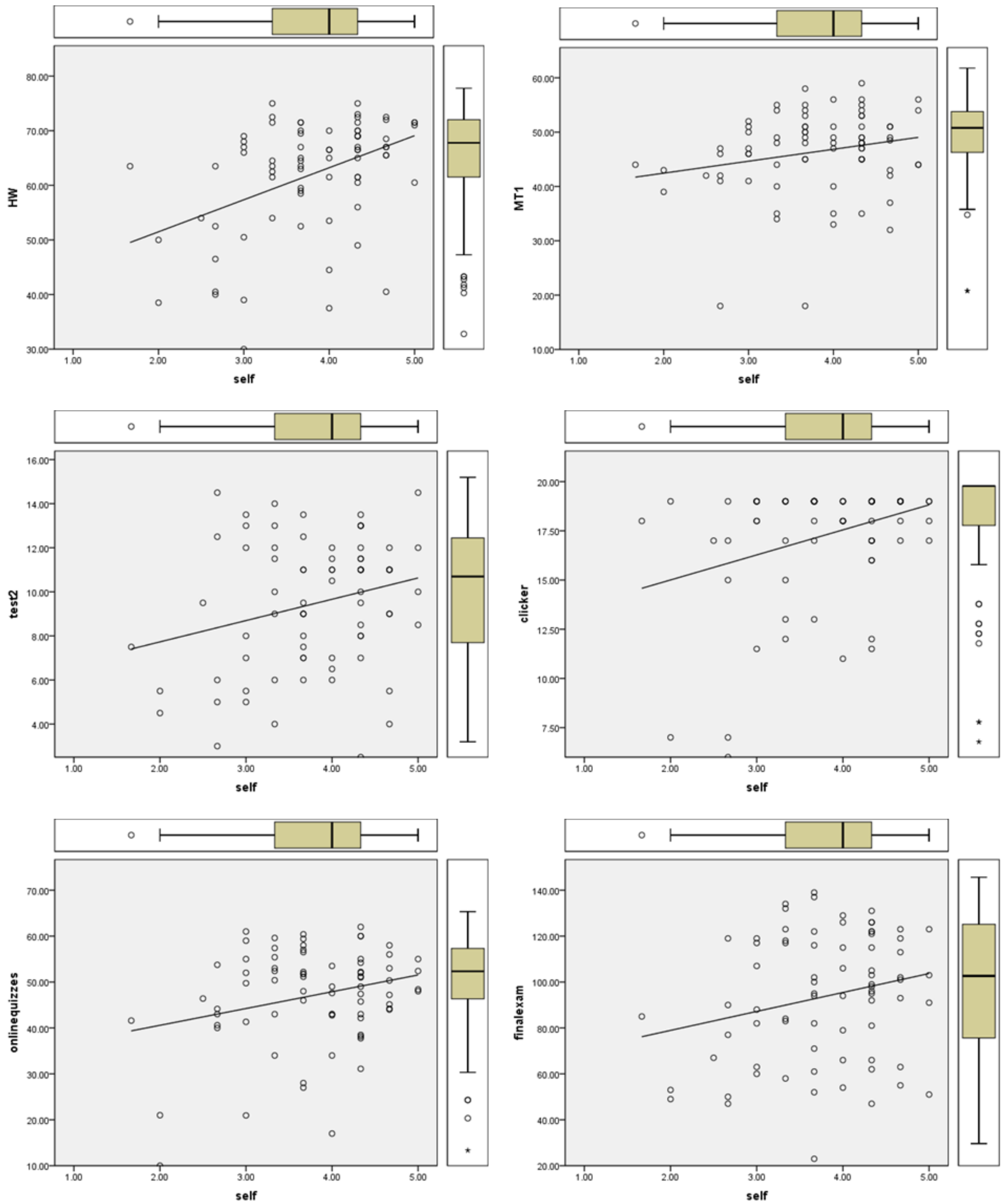
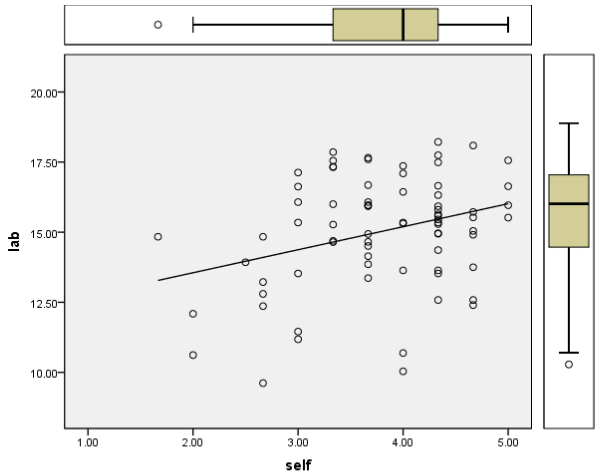
Printed Name of the Participant signing above

Table A-12: Consent Form for Two One-on-One Interviews Plus Study Log

Appendix B Additional Quantitative Data Analysis (Chapter 4)

B.1 Regression Plots between Round$_{SEPT}$ and CHEM 121 Performance Scores

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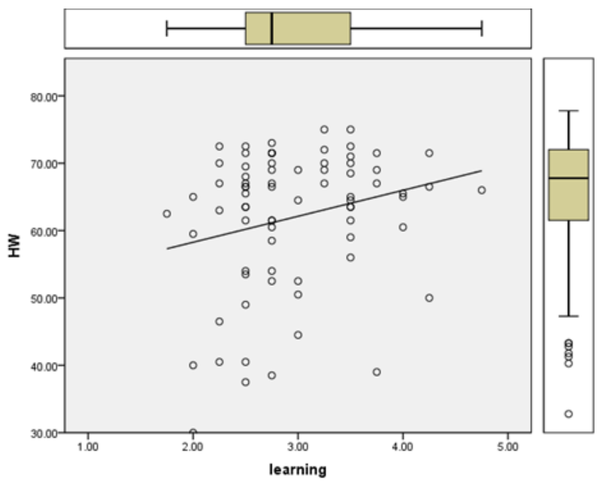
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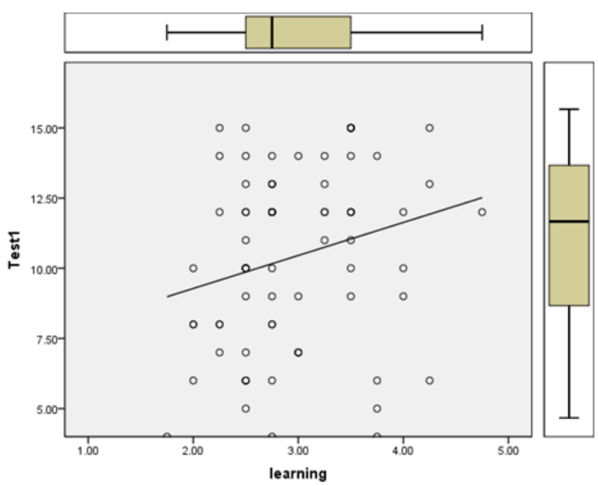
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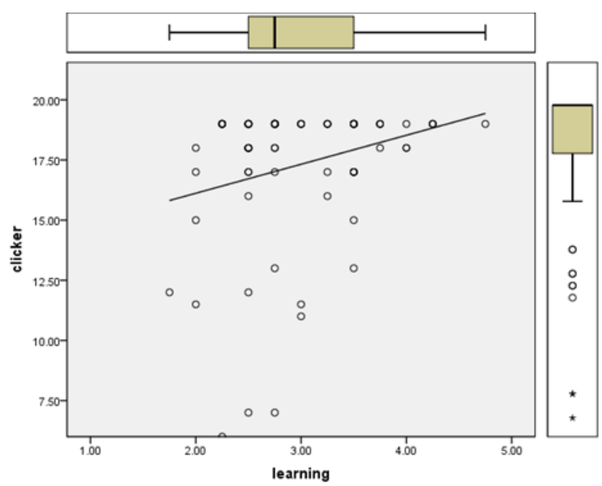
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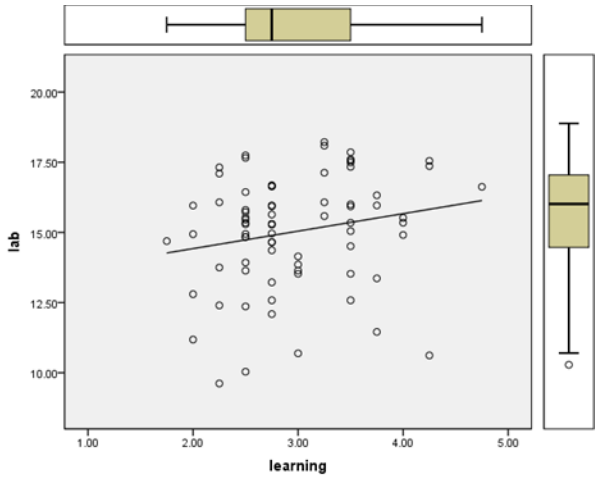

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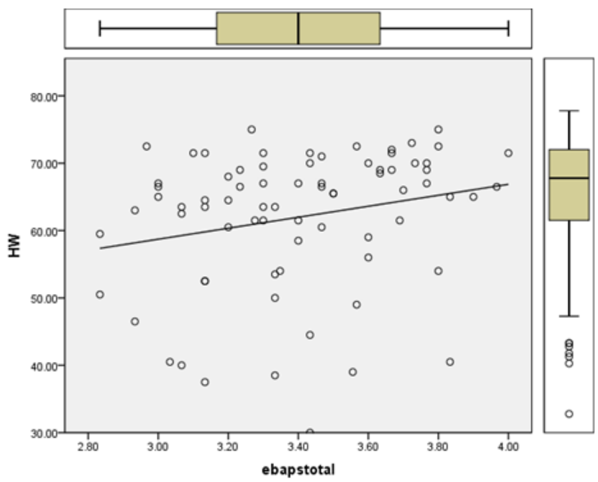

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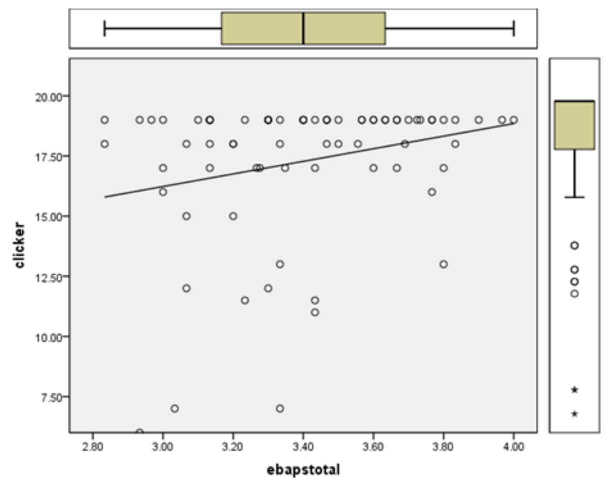

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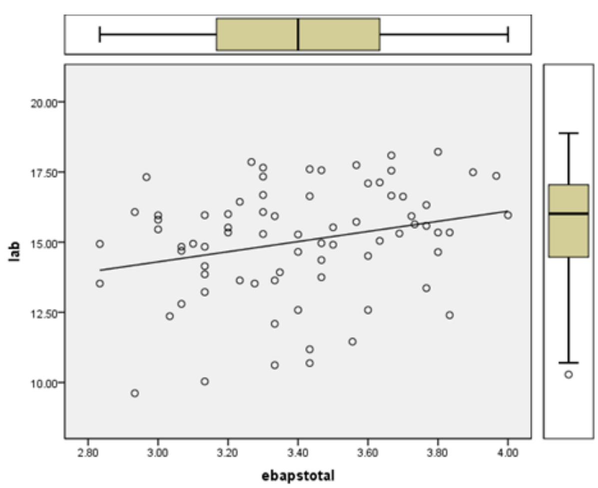

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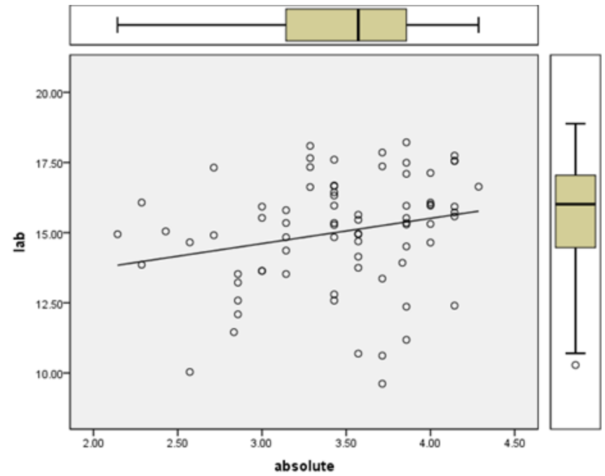
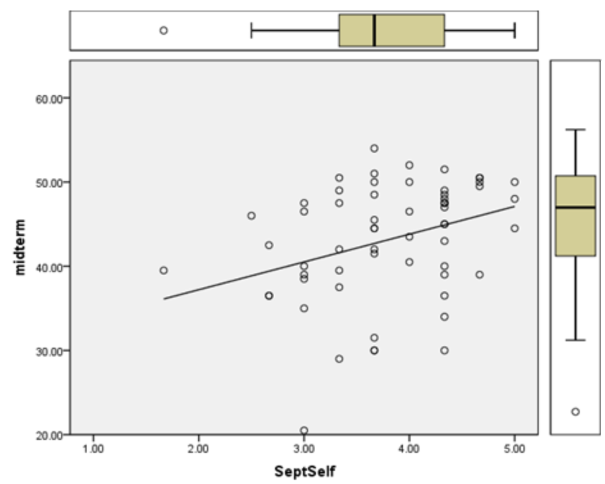
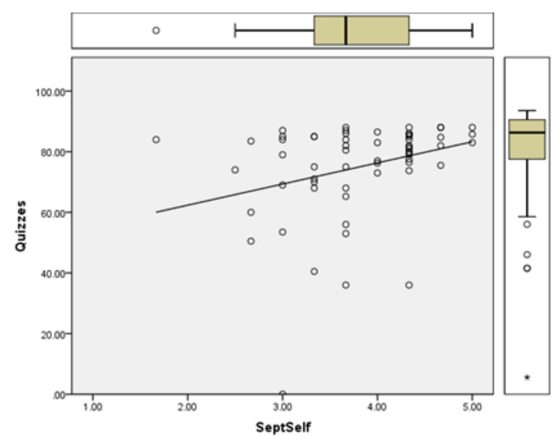
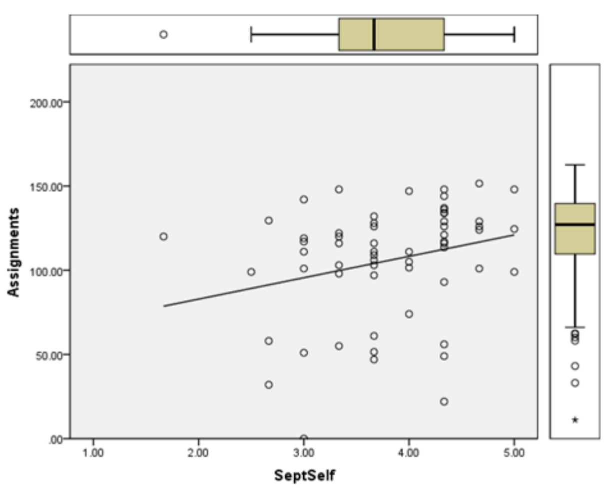
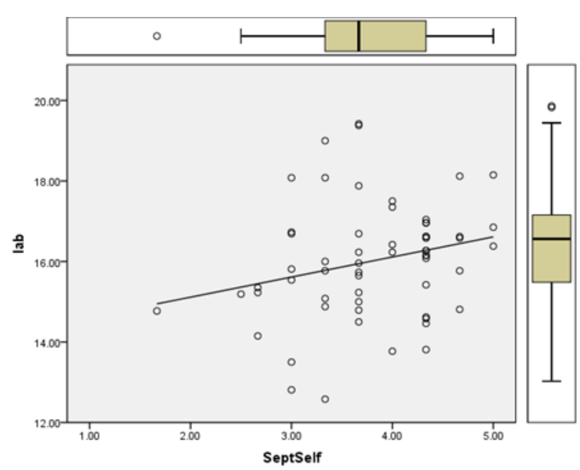


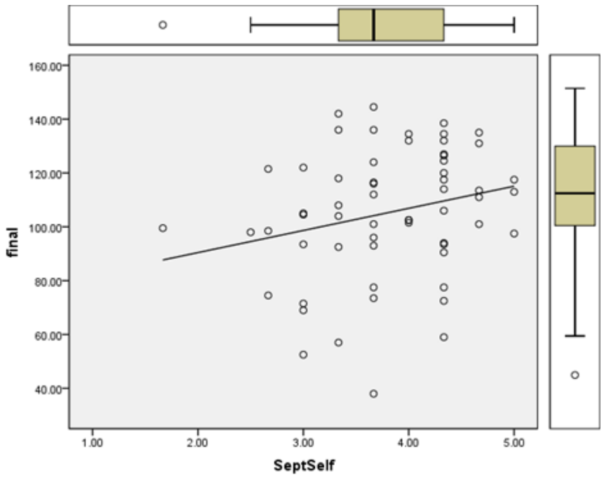
B.2 Regression Plots for Round$_{SEPT}$ and CHEM 123 Performance Scores







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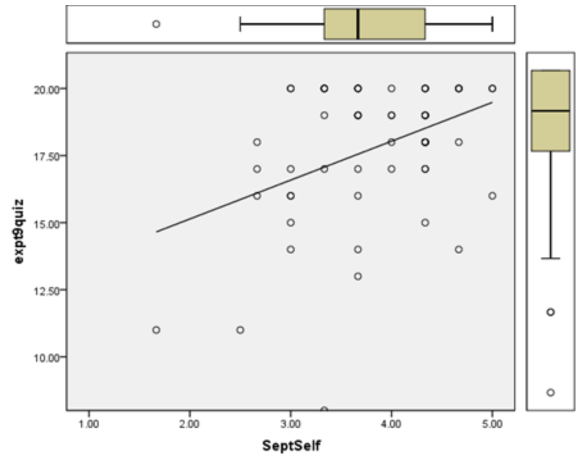
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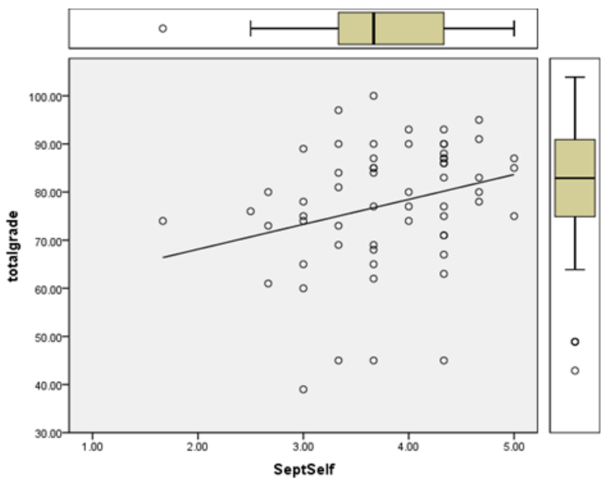
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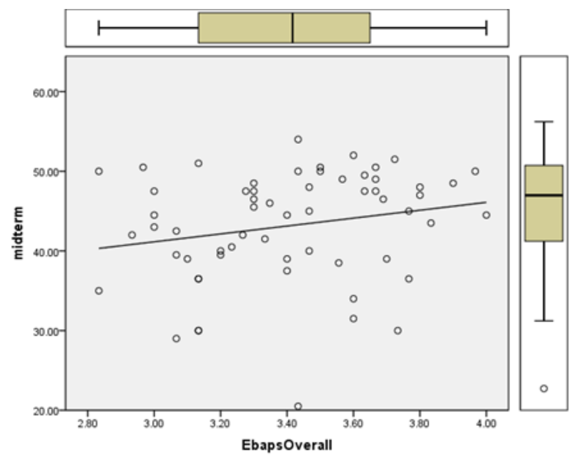
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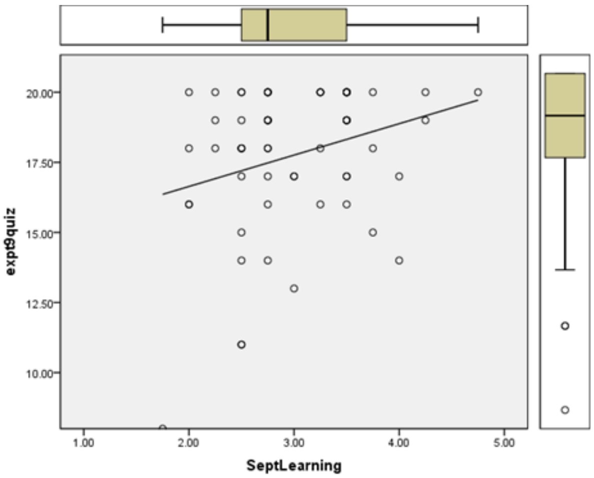
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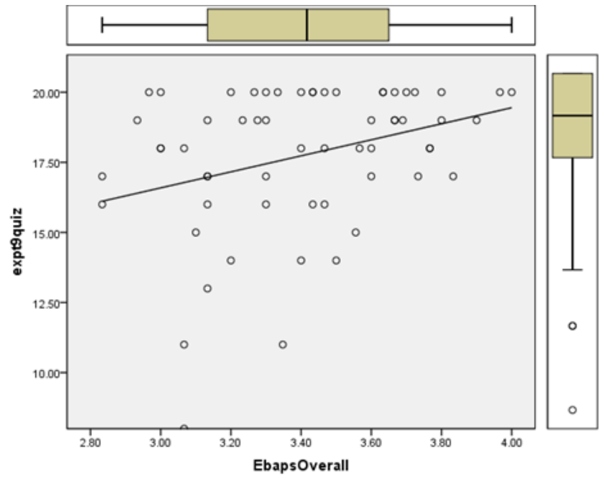
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Appendix C Additional Qualitative Data Analysis (Chapter 5)

Classification of Student Expressed view	Student	Response to *When solving chemistry problems, the key thing is knowing the methods or patterns for addressing each particular type of question. Understanding the "big ideas" or underlying concepts might be helpful for some problems, but not for most regular chemistry problems.*	Example behavior in a task	Classification of approach to problem
Favored conceptual understanding	Alen	I disagree. I think its important to understand the concepts and apply the concept.	Drew and applied the Gibbs energy parabolic curve and answered without any calculations.	Highly conceptual
Favored conceptual understanding	Adam	I disagree that. Because I think it is always useful to understand the general concept to think correctly because if you don't understand the general idea you cant decide what method to use in the question. First when I look at problem, I think what part of knowledge I need.	Does not use any formulas and relies on his chemistry laboratory experience. Even though he gets stuck after I probe him about dG°, he still relies on his experience and sticks to his original (correct) answer.	Highly conceptual
Favored conceptual understanding	Albert	I think the concept is important for solving problem. Every time I solve problem, I review the lecture to see what concept the question relates to.	His first instincts was to look at numbers/equations but then he says, "but from my experience, it will react." Then Albert thinks about it and starts writing. He says I should focus on dG, not dG° so I use this equation (dG = dG° + RTlnQ). He says RTlnQ can be negative so dG can be negative.	Highly conceptual (looks at equation but to confirm concept)
Favored both	Janet	Big ideas are important but I find that I can get away sometimes by knowing the patterns only. It takes longer to learn big ideas or its harder. If I was going to choose chemistry, then I would try to learn the big ideas.	Janet approach the problem by matching the numbers… "I'll write everything I have and everything I can think of- equation wise." She realized that she did not have K_a so she got stuck. She did eventually get to the right answer by drawing the parabolic dG graph. I then ask, why did you not relate the question to your own experience? Janet says, "because it gave me numbers so I thought, I have to do math. Usually, in chemistry, what they give you is what they want you to use."	Starts with patterns then applies concepts.
Favored both	Fancy	Understanding the big concept is fundamental to solving the problem. If you don't know the big concept then you maybe don't know what you are doing. I did solve problems without understanding and using method but most reason is because of my laziness.	Fancy started by writing unrelated formulas and could not solve. She gave up quickly and admitted that she was not comfortable with the topic. For task 2, Fancy was highly conceptual. She says she reviewed the material the day before.	Inconsistent between tasks. Uses both patterns and concepts.
Favored both	Grace	I think you understand the concept, you will do the most practice but if you just for high grades, you don't need the big concept. If you understand the big concept, you can do any problem. But if you just know method, you can just do regular problems and still get good grade. It is better to know the concept but it depends on whether you want to study this subject or not. If you just want to do one course, it is ok to just know the method.	Grace thinks quietly for 1-2 min and then gets answer. She is not jumping to calculation. She says she uses common sense.	Highly conceptual

Favored both	Oscar	That's what we did in high school. The teacher gave us a method to solve a kind of question. Then I can solve a hundred questions. Both big idea and method are important. If you know the big idea but not the method, then you can not solve it. If you only know method, you will not know why so you can not solve a similar problem.	Oscar responds correctly but is not able to explain how he came to the answer. He says, "I think it will react with water. Its truth. I don't know why." It will just react a little bit, not completely. I did not use dG^0. I don't know how! I challenge him about spontaneity. Oscar says dG^0 does not tell you spontaneity, only dG tell you spontaneity. Oscar says he is not confident. I just think the answer, I did not know For task 2, Oscar's approach was to use every formula that seemed related to the question.	Inconsistent in tasks. Used both concepts (although not fully) and patterns.
Favored both	Bowen	What you say right now, helps you with your exam but if you want to really understand, you have to understand the concept first… In my high school, the teacher tell you more about the trick on how to solve the problem but here they teach how this thing happen.	Bowen responds correctly to one of the questions but she can not explain her answer. In task 2, she gets all questions wrong unless I help her! She has all her concepts mixed up.	Uses both patterns and concepts. In task 1, used concepts and was successful but in task 2 used patterns
	Roya	"Both pattern and concept are important. If you know the pattern, which someone solved before, then you can solve the problem. It is easy to forget the pattern if you don't know the concept. If you know concept, you will understand why the pattern works."	She then starts drawing a RICE table. Now she says I made mistake… it didn't give you Ka. Everytime I do this, I get Ka, Kw, Kb but now what do I do. She asks if the question is solvable. I say yes. She struggles. She continues with RICE. She gives pH = 2.37. I ask her why did she calculate pH. Roya stops and laughs. She says, "I naturally wanted to calculate it since all the questions ask for pH." Roya for task 2 also was shaky on the concepts. She kept saying, "I don't know!	Uses both patterns and concepts. In task 1, used patterns and got lost but in task 2 used concepts and succeeded.
Favored patterns	Kevin	I agree that knowing the method is good enough for solving regular problems. He says understanding the concept may require more knowledge.	Kevin draws ICE table and gets stuck. He is unable to answer the question. For Task2, it gets all the questions wrong initially and He asks can we compare Ka and Kb?	Uses only patterns and got lost quickly.
Favored patterns	Jessy	Sometimes I can't understand the big idea so then it is easier to know the method. If I can understand, then it is better to know concept.	She struggles then ask, can I use this formula (dG = dH –TdS). Jessy thinks if dG is positive, then it is spontaneous. She is unable to answer the question. For TASK 2, Jessy asks, Do I need a RICE table? I say no. She then asks if this is acid/base reaction that produces salt and water? She gets more and more confused and is unable to answer the question.	Uses only patterns and got lost.
Favored patterns	Chun	When solving the question, I don't remember the big concept but by learning how to solve it, I remember the big concept.	Chun says its confusing! She begins to write formulas about dS (reversible). She then says she thinks it will react because whenever you are asked an acid/base question, it reacts! I help and give her answer. For task 2, she asks me for a formula sheet. I tell her i don't have one but she can ask me any formula. She says she doesn't know which formula she wants. She then says, she doesn't know. I ask her if she wants to try a bit longer or go through answer. She wants to go through answer.	Uses only patterns and got lost.

Favored patterns	Tayshawn	Yes, I agree. In chemistry exam, we don't have much conceptual questions and mostly just solving questions by using the formulas so we just need to be familiar with formulas and apply the formulas to the question.	Tayshawn: Uses every formula he can think of! RICE table etc. Says he saw numbers and wanted to calculate.	Uses only patterns and got lost.

Table C-1: Details of Problem Solving Strategies