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Implementing Reflective Writing in Combination with Labatorials

by

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Abstract

Students are often not familiar with the language of science and as a result they have great difficulty understanding scientific texts. Students tend to memorize the materials that they see in the textbook without thinking about their meaning, because they believe that language and words hold the knowledge and they need to use the same words and terms in order to show their understanding. Such students who think that knowledge in science is a body of settled facts that comes from authority take a passive role in learning and become a receiver of knowledge, while those who try to make sense of the science language and construct their own understanding by questioning the knowledge presented to them are more likely to develop reasoning and critical thinking skills.

The hermeneutical approach that is the basis of “Reflective Writing” encourages students to question what is presented to them and moves them from receiving knowledge to constructing their own understanding. Reflective writing was used in combination with a new style of introductory physics labs called 'Labatorials' at Mount Royal University (MRU) and the impact of these pedagogical tools on student learning, and in particular on how students learn, was investigated and analyzed in this study. Interviews with students who completed the reflective writing assignments in the introductory physics labatorials as well as an analysis of students’ reflective writing assignments helped us find key aspects that make the reflective writing activity useful to the students. Interviews were also used to find out if Labatorials are helpful to the students.

The disciplined-focused epistemological beliefs questionnaire (DFEBQ) developed by Hofer (2000) was used in this project to find out whether the combinations of reflective writing and labatorials can change students’ epistemology.

With these related projects, we establish three main results. First, we identified the main aspects that make reflective writing an effective learning activity in introductory physics courses. Second, we have also made progress in characterizing the positive and negative aspects of labatorials. Third, we have analyzed the possible changes that the combination of reflective writing and labatorials can have on students' beliefs about knowledge and learning.

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Chapter 1: Introduction

Sitting in an old classroom in the first year of my undergraduate physics degree in Esfahan University in Iran, I was just another quiet student in the crowd of hundreds staring at a professor writing the important parts of the textbook on the blackboard. Some students were trying to take notes and some like me trying to understand what the lecture was about. There was nothing unusual about that class, just another physics class and I was just a student sitting there like the others, except for the fact that I kept thinking "what is the point of sitting there and watching a knowledgeable professor who tried to list a bunch of principles and equations on the blackboard." There was no interaction between him and the rest of the class. There was no assignment or any other activity during the semester and we had to show all we knew during the mid-term exam and the final exam. I kept looking at my watch to get out of the class, but when the class was done the last sentences that I heard changed my life. The professor looked at the crowd and said "if you want to just take a degree you will take it eventually, but if you really want to learn physics and enjoy it, it's your job to make sense of the materials presented in this class." I was frozen in my seat thinking about what the professor said. I wanted to learn physics and enjoy my major but I couldn't find anything interesting in the class to enjoy. How could I make sense of the materials presented when I wasn't given the opportunity to think about them? I was given a body of principles and equations in two hours without having a chance to make sense of them. That moment became a defining moment in my life and left me with many questions about traditional teaching, instructional methods, learning physics and creating an interacting atmosphere. Exploring such questions motivated me join the Physics Education Development (PED) group at the University of Calgary and this gave me the opportunity to have meetings with the instructors who have used alternative methods of teaching and thus to learn about improving teaching in Physics and Engineering. As Gadamer (2013) said, understanding begins when something addresses us. You are chosen out of a crowd. This happened to me when I was sitting in a crowd of hundreds and left with many questions to explore.

1.1 Statement of the Problems

Arnold B. Arons, formerly of the University of Washington and Amherst College, was one of the early leaders in physics teaching and in physics education research. He initiated a paradigm shift in the way science education is presented at the post-secondary level (Kalman 2006). Arons believed that “lucid lectures and demonstrations were depositing virtually nothing in the minds of the students” (p. 3). In “A Guide to Introductory Physics Teaching,” he clarifies his objective as a way “to bring out as clearly and explicitly as possible the conceptual and reasoning difficulties many students encounter and to point out aspects of logical structure and development that may not be handled clearly or well in substantial segments of textbook literature”(Arons 1990, p. vi). Arons (1990) pointed out the unwelcome truth that:

> “much as we might dislike the implications, research is showing that didactic exposition of abstract ideas and lines of reasoning (however engaging and lucid we might try to make them) to passive listeners yields pathetically thin results in learning and understanding except in the very small percentage of students who are specially gifted in the field.” (p. vii).

One problem with the introductory physics courses is that many students have great difficulty solving the assigned problems. Until midway through high school they memorize templates for every situation encountered and so when they enter university they lack the ability to apply principles gained from a problem to another problem that is slightly altered (Kalman, 2006). Some students look at physics as a problem-solving discipline and so they consider the calculated answers as a goal in itself and dismiss the conceptual basis of the problems (2006). The epistemology[1] of these students is different from the epistemology of professors who want students to understand the conceptual basis of the problems (Chi et al., 1981; Hewitt, 1995; Kalman, 2006; Leonard et al., 1995; Maloney, 1994). Paul Hewitt, author of the best selling Conceptual Physics believes that "the professors and the students view solving of problems in a very different way. The professor classifies the problems in terms of concepts, while the students classify them by situations" (cited in Kalman, 2008, p. 10). Kalman (2006) believed that when a student cannot understand the conceptual basis of a problem, he or she would accept the answer gained as a goal and expects you as a teacher to spend as much time as possible working problems in class. This student may think that you are not doing your job when you spend a great deal of time teaching the concepts in the classroom. Why do some students lack the ability to use the principles gained from a problem to other problems that are slightly different? To answer this question we look at the intellectual development of students when they enter college. Students who cannot use the principles gained from a problem to an apparently different one, have not yet developed that ability. This situation is what Piaget characterized as "concrete operational" stage (Ginsburg & Opper, 1988). Many educational psychologists believe that young adults mature through a sequence of stages. Piaget and his colleague Barbel Inhelder are the pioneers in the field of intellectual development (Ginsburg & Opper 1988; Inhelder & Piaget, 1958). On the basis of research concerning children, adolescents, and young adults, Piaget presented his intellectual development theory that explains four stages of knowing: sensory motor, preoperational, early concrete operational, and formal operational. The third and fourth stages

[1] Epistemology is a field of philosophy related to how individuals come to know, and their beliefs about knowledge and knowing (Hofer, 2000). The topic of epistemology is discussed in chapter 3.

are of great interest in college and university teaching. In the third state the adolescents can get knowledge by engaging in mental actions or operations, while at the fourth stage the ways they get knowledge is no longer restricted to concrete operations but can now be formal, abstract, and hypothetical. Table 1 shows the four major periods of intellectual development presented by Inhelder and Piaget (1958).

Age	**Stage**
Birth to two years	Sensory-motor
Two years to seven years	Preoperational
7 years to eleven years	Concrete operational
Eleven years and above	Formal operational

Table 1.1 Periods of cognitive development according to Inhelder and Piaget (1958)

Piaget's theory of cognitive development is well-known within the fields of psychology and education, but it has also been the subject of considerable criticism (Anderson, 2005; Siegler, 1996, 2013). Obviously, a child does not suddenly change on an eleventh birthday from the concrete operational stage to the formal operational stage (Anderson, 2005). Anderson believed that there are large differences among children and cultures, and the ages given are just rough figures. Anderson also believed that careful analysis of the development within a single child fails to find abrupt changes at any age. Siegler (1996) has argued that upon careful analysis all cognitive development is continuous and gradual. Piaget himself always maintained that the stages of development are approximate rather than absolute (Stafford et al., 1976). Despite the critics, an examination of Piaget’s theory shows that even if his theory over simliied the abilities of young children, it is remarkably consistent with students entering college (Lefrancois, 2011). Piaget’s theory has been very influential, impacting psychology and education over the years while also being controversial. Piaget's theory has helped teachers, parents, and childcare workers become fascinated observers of children's development (Lefrancois, 2011).

In considering how to facilitate students' gradual development from one stage to the next it is worth mentioning the stages presented by William G. Perry (1999) for students progressing through university: dualism, multiplicity (early multiplicity and late multiplicity), relativism and commitment (Perry 1999). Table 2 shows the main stages presented by Perry.

In the stage of dualism, any idea or act must be either right or wrong and students in this stage attempt to know and understand in terms of only two categories, for instance the acceptable versus unacceptable, or the familiar versus the strange. Perry explained that "This division is between the familiar world of authority-right-we, as against the alien world of illegitimate-wrong-others. This stage leaves the world of authority free of conflict. Anything that students find different from what the professor says has no potential for legitimacy. Students complement and confirm the rightness of authority instead of calling it into question." A freshman told Perry in an interview that "When I went to my first lecture, what the man said was just like God's word, you know. I believed everything he said, because he was a professor, and he's a Harvard professor, and this was, this was a respected position" (Perry 1999, p.61). Dualism roughly corresponds to the concrete operational stage presented by Piaget. Concrete learners cannot understand abstract ideas without being involved in physical manipulation and are called "object bound." Students at this stage lack the ability to apply principles gained from a problem to an apparently altered problem (Kalman 2006). Arons (1990) believed that concrete operational students are not reasoning when they face a problem but are simply rearranging the symbols, as if they were concrete objects.

Main Stages	**Dualism**	**Early Multiplicity**	**Late Multiplicity**	**Relativism and Commitment**
View of Knowledge	All knowledge is known. There is a certainty that Right and Wrong answers exist for everything. Knowledge is collection of information.	Most knowledge is known. All is knowable (first view of learning as a process that the student can learn). Certainty that there exists a Right Way to find the Right Answers. Realization that some knowledge domains are "fuzzy."	In some areas we still have certainty about knowledge. In most areas we really don't know anything for sure. Certainty that there is no certainty (except in a few specialized areas). Hence "do your own thing" – all opinions can be just as valid or valid as all others.	All knowledge is contextual. All knowledge is disconnected from any concept of Absolute Truth. However, right and wrong, adequate and inadequate, appropriate and inappropriate can exist within a specific context and are judged by "rules of adequacy" that are determined by expertise good thought process.
View of Role of the Instructor	Source of knowledge Role is to give the knowledge to student. Good instructor equals Absolute Authority and Knower of Truth.	Source to right way to find knowledge, of how to learn. Role is to model "the way" or process.	Source of the process of thinking. Modeling the use of supportive evidence – modeling "the way they want us to think" – modeling good methods of scholarship.	Source of expertise. Role of expert-guide-consultant within the framework of "rules of adequacy" and within context. Mutuality of learning is sought. One earns authority through having expertise.
View of the Role of the Student	Role is to receive the information or knowledge and to demonstrate having learned the right answers.	Role is to learn how to learn, how to do the processes called or, to apply oneself, and to work hard.	Role is to learn to think for oneself and to learn to use supportive evidence. Independence of thought is valued.	Role is to exercise the use of the intellect, to shift from context to context, and to apply rules of adequacy to information, concepts, perspectives, judgments.

Table 1.2 Analysis of the learner characteristics of students implied by the Perry scheme (1999)

Diversity appears in many forms to students in the multiplicity stage presented by Perry. In this stage they start interpreting their own experience and have an opinion. They are also aware that other people may come to different conclusions. In this new world of thinking, students can develop a new sense of community among peers in which they can share ideas. Perry believed that in this community there is no "we" against "they", but "we and they" can merge: “a sense that everyone is in the same boat will be of comfort as the student allows himself to see the full implications of his recent learning” (1999). Critical thinking will be added to this community when students go to the stage of relativism. They can make comparison among several interpretations of an event. They learn to accept responsibility in the learning process and so they start learning to think independently and to choose among equally good alternatives to make a commitment to action (Perry 1999). Multiplicity, relativism and commitment correspond to the formal operational stage presented by Piaget. He believed that students in the formal operational stage start developing the ability to imagine the possibilities inherent in a situation. Before acting on a problem they analyze it and attempt to develop hypotheses concerning what might occur (Ginsburg 1988). Renner and Paske (1977) claimed that around 50% of entering college students are concrete operational. In view of this fact, concrete instruction seems to recommend itself to colleges for the first two years (Kalman, 2006). After conducting five studies, Prigo found that “approximately 50% of incoming college students have not reached the intellectual stage of development where they can think abstractly (i.e. scientifically)” (cited in Kalman, 2006, p. 9). Arons and Karplus (2002) also stated that:

> “Although the various investigations are beginning to reveal significant and interesting differences between social and economic groups, the grand averages have been emerging, with very little variations throughout the age and school level spectrum: about one-third have made the transition to formal operations, about one-third can be regarded as in the process of transition, and about one-third use primarily concrete patterns of reasoning.” (p. 205).

It is really up to us as teachers to move our students to a higher level of intellectual thinking (Kalman 2006). In teacher-centered instructions the students are not given the opportunities to build their own understanding of materials, instead knowledge is poured into them as a body of settled facts by an authority. Piaget (Ginsburg & Opper, 1988; Inhelder & Piaget, 1958) believed that knowledge is not given to a passive observer; rather, knowledge of reality must be discovered and constructed by the activity of the student. Various kinds of student-centered instruction give students the opportunities to value and examine their views and can help them develop intellectually (Kalman 2006). Within this context, it is essential to create a constructive teaching and learning environment for students to learn actively. This means that instructors in science courses cannot rely only on lectures to reach students. It is necessary to supplement the lectures with other activities to create an inquiry-based course (Kalman 2008; Mulhall 2008; Redish 2000).

Students entering the classroom in an introductory science course face many difficulties. Kalman (2006) mentioned the difficulty of reading and understanding the material as presented in their textbook as one such difficulty. Arons (1990) mentioned the reasoning and understanding the physics concepts as the fundamental gaps in the background of students entering an introductory physics course. He believed that the concepts should have been mastered at earlier levels in the schools, but unfortunately such mastery has not been achieved. Arons (1990) explained some examples to shed light on these gaps: “one of the most severe and widely prevalent gaps in cognitive development of students at secondary and early college levels is the failure to have mastered reasoning involving ratios” (p. 3). There are many ratios in introductory physics courses such as density, average velocity, and acceleration. It is important for students to be able to interpret verbally the meaning of a number obtained from a particular ratio. Many students have great difficulty giving verbal interpretations of the most basic concepts in physics since they have almost never been asked to do so. Arons (1990) believed that:

> “without such practice in at least several different contexts, students do not think about the meaning of the calculations they are expected to carry out, and they take refuge in memorizing patterns and procedures of calculation, manipulating formulas, rather than penetrating to an understanding of the reasoning.” (p. 4).

As an outcome, when they find themselves outside the memorized situations, they cannot solve problems that involve reasoning. It is necessary to create the activities that lead the students to articulate the interpretations and explanations in their own words (Arons, 1990). One of the reasons why students memorize the scientific terms and definitions without thinking about their meaning is that they are not familiar with the language of science (Arons, 1990; Eger, 1992; Christiansen & Kirby 2003; Kalman & Rohar, 2010). The language of science is a language that scientists use to talk about nature (Eger, 1993). Students are not familiar with this language and so they have great difficulty understanding it. Since textbooks are also written in the language of science, students have troubles understanding scientific texts (Kalman & Rohar, 2010; Eger, 1993). Students have a strong tendency to memorize and mimic language, because they believe that language itself holds the knowledge, and they need to participate in using it in order to show their knowledge (Arons, 1990; Eger, 1993; Kalman & Rohar, 2010; Packer, 2010). Eger (1992) believed that memorizing the terms and definitions without thinking about the meaning and understanding the concepts is the most important problem for science education and called it “the problem of meaning”. Some philosophers like Dilthey believe that the role of natural sciences is to explore cause and effect relationships, while social sciences seek understanding of meaning (Packer, 2010). Eger (1991) argued that understanding of the meaning in science beyond its role in uncovering causal relationships is an important issue that must be considered in science education. In this project we are trying to address student’s difficulties in trying to understand the materials presented in the textbook. To encourage students to make sense of the materials presented instead of memorizing them, we also address the problem that students usually take a passive role in learning physics instead of being a part of the learning process.

1.2 Proposed Strategies to Address the Problems

I joined Mount Royal University (MRU) in August 2012 and started my job as a senior physics lab instructor in the department of chemistry and physics. A motivated group of instructors, lab instructors, and lab technicians joined me to revise and improve the introductory physics labs. This group helped me in collecting data and consent forms in this study. In an effort to create a constructive learning environment and help students with the problem of meaning, we have used a writing activity called “reflective writing” (Kalman, 2008) in a collaborative group laboratory called “labatorials” (Ahrensmeier et al., 2012) in the introductory physics courses taught in MRU. One of the most important reasons behind using reflective writing in introductory physics courses is to create an active learning environment in which students are given the opportunity to articulate lines of reasoning and explanation in their own words and think about the meaning of terms and concepts presented in the textbook. This thesis introduces using reflective writing in a non-traditional laboratory called “Labatorial” in introductory physics courses in MRU. My supervisors (Dr. Calvin S. Kalman and Dr. Robert Ian Thompson) and Dr. Kalman’s research group (Ahmed Ibrahim, Xihui Wang, and Wahidun N. Khanam) helped me with the process of data collection and analysis in this study.

Writing-to-learn strategies are often appreciated as activities that, when put into classrooms in specific disciplines, not only help students learn to write in the methods of that discipline but also help students learn content knowledge (Connolly, 1989; Kalman, 2006;

Mullin, 1989). To get students to actively construct[2] their own understanding, the emphasis of writing tasks should be based more on reflection about what they understand and on scientific reasoning and interpretation. Interpretation and reasoning are related to the topic of hermeneutics[3] that will be discussed in Chapter 2. Based on the literature review we know that 'reflective writing' is a helpful learning activity (Huang & Kalman, 2012; Kalman, 2011; Kalman & Rohar, 2010; Kalman et al., 2008). Therefore, in this study the primary research question is:

1. How is reflective writing helpful at achieving effective students learning outcomes?

In introductory physics courses in MRU, students provided their reflective writing assignments before doing labatorials. Therefore, the secondary research question is:

2. How are 'labatorials' helpful in introductory physics courses in MRU?

Based on the studies done by Kalman's research group on reflective writing activity (Huang & Kalman, 2012; Kalman, 2011; Kalman & Rohar, 2010; Kalman et al., 2008) and the pilot study that we conducted in fall 2013, we hypothesized that reflective writing encourages a hermeneutical approach to science, improves students learning strategies, and in combination

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[2] The term "construct his/her own understanding" might not mean "proper" understanding. While constructivism claims that we learn by constructing our own understanding, this understanding might be wrong in some cases. If a student constructs his own understanding of some concepts, this does not mean that it is the intended meaning in books and other materials. In reflective writing, students do not lose any mark if their explanation of the concepts is not consistent with the materials presented in the textbook. They are asked to identify any conflict between their explanation and the materials presented in the textbook and formulate a question about the conflict. I am aware of the fact that in some cases "constructing understanding" is the expected understanding by the course. However, this is not what I mean by using "constructing understanding" in this study (Connolly, 1989).

[3] Hermeneutics is the theory of interpretation. Hermeneutics is used to interpret secular texts, cultural experiences, and indeed all forms of phenomena and human activity (Packer, 2010; Howell, 2012).

with another interactive intervention can change students' epistemological beliefs. To address the main research questions and test our hypothesis we developed some sub-questions that are discussed in Chapter 4. To test our hypothesis about students' epistemological beliefs and also to make a connection between the main research questions, we studied whether the combination of 'reflective writing' and 'labatorials' can changes students' epistemologies during the semester.

The studies culminating in this thesis are an aggressive start to address these complex questions. This thesis presents a mixed methodology study aimed at understanding how reflective writing and labatorials are helpful learning activities. This study consists of two main parts: (1) The winter 2014 – fall 2014 study focuses on students' perspectives on reflective writing in introductory physics labatorials, students' pre-understanding which is related to the topic of hermeneutics, the analysis of students' writing products, and students perspectives on labatorials; (2) The fall 2014 – winter 2015 study focuses on students' epistemologies and any possible change in students' epistemology as a result of combining reflective writing activity with labatorials. In Sections 1.3 and 1.4 I present an introduction to reflective writing activity and labatorials respectively. Section 1.5 provides a summary of research done in the field of writing-to-learn, writing in learning science and more specifically physics.

1.3 Reflective Writing (RW)

An increasing number of courses in physics and engineering require students to write reflectively. Reflective writing is an informal writing activity to help students find out the meaning of the materials presented in the textbook (Kalman, 2008). Kalman (2006) believed that reflective writing is evidence of reflective thinking. This writing activity usually involves looking back at something and trying to analyze the event or idea. It also involves thinking in depth about what the event or idea means for you and your ongoing progress (Kalman, 2006).

Kalman (2006) has used the term zone of proximal development (ZPD) presented by Vygotsky (1980) to emphasize the importance of 'self dialogue' in reflective writing activity. Vygotsky believed that teacher guidance and collaboration with peers can help students in solving a higher-level problem (Vygotsky, 1980; Kalman, 2006). We have talked about the developmental stages presented by William G. Perry: dualism, multiplicity, relativism, and commitment (Perry 1999). For example if three students in the introductory physics course are at the dualism stage, these students on their own can deal with the learning tasks at the level of the duality developmental stage. By providing guidance or by encouraging collaboration among peers we can enable these students to solve a higher level problem and so these students are not at the same developmental level. ZPD "is the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under guidance or in collaboration with more capable peers" (cited in Kalman 2006, p. 13). Discussing the problems with peers can scaffold students into developing the solution. Kalman (2006) believed that reflective writing could also provide scaffolding for students by encouraging self-dialogue. Reflective writing involves a self-dialogue to explore the meaning of the physics concepts presented in the textbook without having another person present. To help students construct their own understanding of concepts and become active learners, we ask students to do reflective writing before going to labs. Students read the sections of the textbook related to each experiment and write down their own understanding of concepts. The idea of doing reflective writing is to construct a self-dialogue about what they have read. The main difference between summary and reflective writing is that in a summary writing they write down what they already have in their mind during their reading, while in doing reflective writing they question what they read and relate it to other concerns. Students are expected to write their own understanding of the concepts presented and provide real world examples. It is also important to make a connection among various concepts. Huang and Kalman (2012) provided instructions for students on how to do reflective writing. We have used the same instruction for students in MRU:

> “Many of you may have experienced that discussion with others helps you clarify your ideas and scaffold you into developing solutions to the problems. Speaking to someone else helps you gain a better understanding. The idea of doing reflective writing is to provide an opportunity for students to construct a self-dialogue that is used to explore the concepts in the textbook without having another person present.” (Huang & Kalman, 2012, p. 93).

To start doing reflective writing, students are asked to first choose a section of the textbook that will be covered in the next labatorial and then start reading the chosen section carefully. They are asked to try to focus on the concepts that they don’t understand and the ones they want to be clarified. They can use any technique that they usually use to read and understand a material such as underlining, highlighting, summarizing, and rereading. After finishing this task, they must write down their own understandings of the section they read. They can use their prior knowledge from previous chapters, courses, or even their own experiences. Reflective writing is not essay writing and they are instructed not to be worried about grammar. When they are finished, they are asked to re-read their writing reflection and compare what they wrote with what they see in the textbook. This helps them find out whether their understanding is consistent with what the text says. If there is any contradiction, they are asked to try to find out the reason. They can reread the section and rethink about the contradiction. They are instructed to follow the same steps until their own understanding of the concept is consistent with the text.

They don’t need to be worried about whether or not what they write is correct since marking is not based on that metric (Huang & Kalman, 2012).

We have been using the rubric (Appendix A) developed by Kalman, Milner-Bolotin, Antimirova, Aulls, Charles, Huang, Ibrahim, Lee & Wang (2012) to mark the reflective writing assignments of introductory physics students in MRU. The rubric was given to the students in the courses.

1.4 Labatorial

In an introductory physics courses with around 200 first year students at MRU, traditional laboratory experimental exercises were replaced by labatorials developed by the Physics Education Development group at the University of Calgary (Ahrensmeier et al., 2012). A physics instructor (Dr. William Scott) and a lab technician (Eric Scott) helped me design and improve labatorials in MRU. The labatorials in the University of Calgary were inspired by the introductory physics tutorial system in the University of Washington (McDermott & Shaffer, 2001). The curriculum used at the University of Washington is entitled "Tutorials in Introductory Physics" and was written by the Physics Education Group at the University of Washington. The Tutorials are worksheets that require students to work through concepts that have been identified by research to be particularly difficult. Some require students to perform experiments and answer the tutorial questions based on their observations. However, there is still a traditional laboratory system for the first year physics courses at the University of Washington. Even if laboratory work plays a crucial role in learning physics concepts, there is little research done on the educational influence of physics laboratory on students (Sokoloff et al., 2007). Based on our experience and the published reports we know that many students believe that traditional physics laboratories are uninteresting and tiresome (Sokoloff et al., 2007). In the traditional physics laboratories, students spend 2 or 3 hours collecting data, carrying out calculations, plotting graphs to present the results gained and verify a relationship. Engaging computer technologies such as microcomputer-based laboratory (MBL) tools have enhanced laboratory programs due to real-time collections, display and analysis of data in introductory physics laboratories (Sokoloff et al., 2007). Before using labatorials in MRU, we were using electronic sensors, microcomputer interface, and DataStudio software in the physics laboratories for data collection and analysis to help students see the data and graphs in real time. However, students were required to prepare a lab report, which was handed in to the lab instructor, marked, and returned the following week. Therefore, students received feedback after the course material had progressed to another topic. In addition, there was no incentive to review comments or to work out the correct answers. Even if DataStudio software displayed various physics concepts such as position, velocity and acceleration in real time, the interpretations of many students in the lab reports were not consistent with their observations and the materials taught. To address this problem we started using labatorials in which students receive instant feedback in the lab. A main purpose of using labatorials in the Chemistry and Physics Department at MRU is to provide ongoing feedback that is advantageous both to students and to instructors during the semester and give students the opportunity to establish a dialogue with each other through group activities.

The name “labatorial” comes from a combination of “laboratory” and “tutorial”. The major goals of using labatorials in introductory physics labs are to help students: (1) gain a better understanding of the physics concepts; (2) investigate the application of physics principles in real life; (3) improve their experimental and analytical skills using MBL tools; (4) value their preconceptions and compare them with their observation; and (5) interact with their peers and the lab instructor in a collaborative learning environment.

There are differences between MRU Labatorial offerings and the original Labatorials developed at the University of Calgary (UofC). Labatorials at MRU carried forward many of the goals and approaches of the original UofC Labatorials, although the implementation differed in some details, including (a) a shift from UofC's team teaching model of 4 lab instructors sharing 48 students to 1 instructor for each group of 16, (b) a shift from UofC's use of a combination of graduate teaching assistants (TA) and undergraduate learning assistants (LA) to MRU's use of dedicated, professional lab instructors, and (c) UofC's use of weekly training sessions for TA & LA lab instructors is adjusted in form at MRU due to the year-to-year stability of the MRU lab instructor roster.

In this new style of lab, students use a worksheet with conceptual questions, calculation problems, and instructions for the experiment and computer simulations (The Physics Education Technology (PhET) project creates simulations for teaching and learning physics and makes them freely available from the PhET website: http://phet.colorado.edu) (Perkins et al., 2006). Labatorials highlight the physics concepts covered in lectures and encourage students to present and share their ideas with one another. Each labatorial worksheet starts with conceptual questions and then asks students to make predictions. After doing the experimental part, students need to explain whether their results support their prediction or not. Each lab section has one lab instructor assigned to a maximum of 16 students.

The traditional labs were oriented more toward experimental methods, while in labatorials students work on conceptual questions and experimental methods related to these concepts (Ahrensmeier et al., 2012). Each labatorial focuses on one physics concept (e.g. uniform circular motion) that has been taught in the class one week prior to the labatorial session (Appendix B). We try to address typical student misconceptions while designing the labatorials

(Ahrensmeier et al., 2012). For example, many students believe that tension is the centripetal force in a pendulum. As you see in appendix B, we asked students to draw a free body diagram for a cylinder hanging from a string when it is not moving. We also asked them to draw a free body diagram at the lowest point when the cylinder is moving. In the experimental set up the string was tied to a force sensor. Most students believed that the force measured by the force sensor is the centripetal force. However, when they calculated the centripetal force using the velocity, mass and length of the pendulum ($F_c= mv^2/r$), they found that the calculated result was not consistent with the force measured by the force sensor. We asked students to call the lab instructor and discuss the possible explanations. Discussion is a part of labatorial and students work in groups of 3 or 4. There are usually 3 to 6 checkpoints in each labatorial. The labatorial worksheets are prepared and tested such that students who arrive on time and concentrate on the material can finish all checkpoints in the time allotted. The purpose of the checkpoints is to encourage an ongoing interaction between the students and lab instructor and provide a feedback in the lab. Each time the students reach a checkpoint, they review the answers with the lab instructor. All students in one group must have the same answers. If the answer to a question is wrong or students are not proceeding in the right direction, the lab instructor leads the students to find the correct answer by themselves, exploring and discussing alternative ideas. Students do not need to write a lab report. When all students in a group reach the final checkpoint, the lab instructor marks their worksheet in the lab.

I evaluated some planned labatorials at weekly physics education research meetings at the University of Calgary and two undergraduate physics students performed them to make sure that the questions were clear. These two undergraduate physics students were active members of Physics Education Development (PED) group of University of Calgary and volunteered to help me develop the labatorials for the Mount Royal University. The first time we applied labatorial style labs in Mount Royal University we had two hour weekly training sessions for lab instructors during the first semester to familiarize them with labatorial goals and strategies. We continued our training sessions during the second semester. We believe that training and discussion sessions for lab instructors are a vital part of labatorial activity.

There is a post-test at the end of each labatorial which contains 10 conceptual multiple choice problems about the topic of the experiment. Some questions were derived from resources such as Controlled-Source Electromagnetic (CSEM) surveying that try to address students' conceptual knowledge of electricity and magnetism (Maloney et al., 2001) and also from conceptual questions at the end of each chapter in the textbook.

1.5 Literature Review

In this part of the thesis first I provide a summary of research done in the field of writing-to-learn in Section 1.5.1 and then I focus on writing in learning science and more specifically physics in Section 1.5.2. We will see that evidence for effectiveness of writing in learning physics is mostly anecdotal, and few quantitative and qualitative research works inform these prejudices. The exception is that there have been qualitative studies done on the effectiveness of a new method of writing called 'reflective writing' in combination with other activities such as collaborative group work and class discussions in Concordia University (Kalman, 2008).

1.5.1 Writing to Learn. Writing-to-learn strategies have become increasingly respected in science and engineering courses and most publications in this field claim that writing helps students learn the discipline, and a large budget has been committed at many universities to supporting writing activities. For instance, Mount Royal University (MRU) has devoted a large budget to provide writing courses called "Creative Writing" to improve students' writing skills in a wide range of topics from graph interpretations to writing a life story. Students at MRU are being asked to write more in introductory courses, and different programs in MRU want their students to have more writing skills for the job market. Combined with the desire of many educators to have students have the ability to explain the course content knowledge clearly in their own words, it would seem that writing activities would be important and useful in physics courses. However, the question of whether writing helps learning in the discipline is open to debate, and data either qualitative or quantitative is needed before such claims can be made.

Writing-to-learn strategies have become increasingly respected in science and engineering courses (Connally 1989; Countryman 1992; Holiday et al. 1994; Kalman 1996; 2001; 2006; 2008; 2010; 2011; 2012; McDermott 2010; Pugalee 1997; Rice 1998; Wallace et al. 2004). Rivard (1994) noted that writing-to-learn can improve the learning of science content, and also that writing as a response is intimately connected to thinking. Indeed Bangert-Drowns et al. (2004) pointed out “writing can prompt and support the use of cognitive learning strategies” (p. 32). Years of research have shown that writing to learn strategies are helpful for students in confronting and becoming aware of misconceptions and strengthening their conceptual knowledge (Connally 1989; Hand, Hohenshell and Prain 2004; Hein 1992; Sutton 1992). Hand et al. (2004) reported an improvement in the students’ performance on conceptual questions when engaged with a series of writing tasks. Emig (1977) believed that writing involves integration of ideas and the relationship among then. It also provides immediate feedback, and increases personal involvement with the material. Many students consider physics as a problem solving discipline. Leonard et al. (1995) studied the role of conceptual knowledge in solving problems and presented qualitative strategies for solving problems. Their qualitative strategies included the use and application of physics principles and concepts in introductory physics courses. Leonard et al. (1995) believed that novice learners usually manipulate equations in an attempt to isolate the desired unknown and rarely consider the conceptual knowledge behind the problem. In contrast, experts first consider the principles and concepts and then look for a mathematical way to implement the principles and concepts. They believed that an activity that helps students identify the major physics principles and concepts and helps them to articulate the rationale for using a particular physics principle or concept can improve their problem solving skills. Leonard et al. evaluated student understanding of concepts and principles within the context of problems solving by asking students to write about the strategies that they took to solve problems during an exam. Leonard et al. (1995) believed that the writing-to-learn method is intended to help students be better problem solvers and writing about the ways of solving problems provides students with an opportunity to reflect on their own problem solving strategies. In addition, a writing activity that reflects student problem solving strategies offers instructors a window into students' conceptual understanding.

As students I have interviewed have stated: writing would help learning; it's like explaining and making sense of the materials and when you explain something it helps you gain a better understanding. It is of great interest to explore why and how they have found writing helpful in learning introductory physics. As educated people, we are used to reflecting on what we are saying and reading. Now the question is do we give our students opportunities to reflect about what they read and if the answer is positive, do our students reflect when we ask them to write something? To get students to actively construct their own understanding, the emphasis of writing tasks should be based more on reflection about what they get (Hand, Prain & Wallace 2002; Kalman, 2006) and on epistemology and scientific reasoning and interpretation (Hand, Lawrence, & Yore, 1999; Hand, Prain & Wallace, 2002; Kalman, 2006). Research supports the need for active engagement to improve learning (Hake, 1998). Writing could be an active engagement activity, and many instructors who use writing in their classes claim that it is (Connally, 1989; Kalman, 2008; Richard, 1998). Reflective writing is a part of the writing-to-learn process to incorporate informal writing into all disciplines (Connally 1989; Kalman 2008). It emphasizes the active learning on the student's part (Kalman 2006). Kalman (2006) believed that reflective writing is evidence of reflective thinking and usually involves looking back at something and trying to analyze the event or idea. Reflective writing asks students to negotiate meaning and establish a dialogue with the textbook to write down their own understanding of the material. It is not simply a recall of main points in the textbook that students usually do in a summary writing. Based on the literature and knowledge about active learning, I believe that writing won't be as helpful unless students are reflective while they write. Hillocks (1995) has explained in detail the ways to teach writing as a reflective practice. There are examples provided in his text showing writing that lacks reflection and writing that contains reflection. Hillocks (1995) believed that not only writing must be taught in order to be a method for creating meaning, but also it must be taught as a reflective process.

Gary Schumacher and Jane Nash (1991) provided a brief review of evidence for the writing-to-learn method and quoted Langer (1986) "few studies have been undertaken to learn what people learn from writing, what different kinds of learning result from different kinds of writing experiences, or how writing can be used to help students understand and remember the material they have read" (p. 68). In the field of writing activities to learn science, there is little research-based evidence to show whether they aid learning within the disciplines. The majority of publications discussing innovative uses of writing in the classroom consist of discussing the activities, stating why the instructor feels they are beneficial, and giving unreliable evidence for their benefit such as the comments left by students that show they were a good addition to the course.

There are two major problems associated with this type of publications. First, we do not truly know if those writing activities were successful since there is usually no supporting evidence for the concluding reports made. Second, if they really were helpful, we do not know how those writing activities were helpful and what specific characteristics of the activity made it successful. Due to these two main problems it is not likely to find out if these activities could also be helpful in a different discipline and environment. That is why besides introducing a new writing activity in introductory physics courses in MRU, the main purpose of this project is to find out how this writing activity helped students during the semester. I will present a summary of works done in the field of writing in learning science and a summary of the published studies on the use of writing in physics classes to show the important development in this area and evaluate the strengths and weaknesses of previous research.

1.5.2 Writing in Learning Science. Although there are many studies in the field of writing-to-learn science, there are very few studies on writing in physics classes. Among the studies in this field, a common point is to include writing in the classes because the authors believe that it will be beneficial to their students.

As Paul Connolly (1989) stated:

> "Writing to learn is less about formal uses of writing to display memory and test mastery than it is about informal writing; about language that is forming meaning; about writing that is done regularly in and out of class to help students acquire a personal ownership of ideas conveyed in lectures and textbooks... The writing-to-learn movement is fundamentally about using words to acquire concepts." (p. 3)

As Connolly (1989) explained, topics such as mathematics and science are about having a successful way of addressing questions and working on problems and therefore they are more about the process than the answer. The lab report as the most common science course activity often include a report of the correct results, not the reasoning and wonderings. Connolly (1989) believed that when all the students in the class obtain the same results to an activity, and there is only one scientifically acceptable outcome for each question, the learners realize that they must somehow generate, copy, or paraphrase the knowledge claim that is desired by the teacher. Therefore, the important feature of education becomes saying the right words, not learning how to use one's own words (Connolly, 1989). In science, the focus of writing should be to understand the meaning and the concepts of the results rather than just reporting them. Many studies in writing-to-learn field use cognitive theories such as the ones developed by Bereiter and Scardamalia (2013) to show the benefits of writing activities in the classroom. However, there are very few studies to explore students' perspectives on writing activities to find out why and how they find writing helpful in studying science. That is why a main purpose of this thesis is to explore students' perspectives on using reflective writing in labatorials to find out how reflective writing and labatorials are helpful.

Students have a strong tendency to memorize and mimic language, because they believe that language itself holds the knowledge, and they need to use the same word to show their knowledge and please the instructors (Arons, 1990; Connolly, 1989; Kalman, 2006; Packer, 2010). Packer (2010) explained that such students believe that every word has a meaning and the meaning reflects the word. Reddy believed that this point of view "objectifies meaning in a misleading and dehumanizing fashion. It influences us to talk and think about thoughts as if they have the same kind of external, intersubjective reality as lamps and tables" (cited in Packer, 2010, p.54). Allowing more non-traditional writing may help students think for themselves, even if their writing products are not clear at first and promote the construction of explanations of the contents. A part of the reason we use a combination of two non-traditional writing activities (reflective writing and labatorials) in physics courses in MRU is to promote the construction of explanations of how and why the world works in a certain way, as contrasting to language that repeats dogma. Labatorials include some activities that give students opportunities to test their predictions and analyze the data obtained. By including questions such as what did you observe? How do you explain your observations? Why are the results not consistent with their predictions? We encourage students to state what is unclear, which allows them to be more aware of their knowledge. In addition, this can help both the students and instructors recognize and confront misconceptions.

A summary of the published studies on the use of writing in physics classes is presented here. The studies are organized based on the individual authors. This is possible due to the small number of published studies on writing in physics. This presentation approach was developed from a thesis in the field of writing-to-learn physics in the graduate school of the Ohio State University (Demaree, 2006)[4]. This information is useful in clarifying what this thesis will add to the research done in the field of writing in learning physics.

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[4] The way I have presented the work done in the field of "writing-to-learn in physics" was inspired by a thesis in the field of writing-to-learn physics in the graduate school of the Ohio State University (Demaree, 2006). A complete literature review and independent searching were done in this thesis, but the way of presenting each researcher's work with advantages and disadvantages was inspired by Demarree's thesis. Writing in physics has been used in other universities such as Marquette University[1], York University[2], and the University of British Columbia[3], but there are not published papers explaining the activities or report studies done in this field.
1(http://researchguides.library.yorku.ca/content.php?pid=224857&sid=5085692)

2(http://www.marquette.edu/wac/departmental/MarquetteUniversityWritinginPhysics2.shtml)

3(https://courses.students.ubc.ca/cs/main?pname=subjarea&tname=subjareas&req=3&dept=ENPH&course=459)

1.5.2.1 Dr. William J. Mullin. Dr. William J. Mullin (1989) is a professor in the Physics Department at the University of Massachusetts at Amherst. In 1982 the faculty senate at the University of Massachusetts issued a call for junior-level writing course proposals from all major-offering academic units. The senate mandate specified that such courses were expected to enhance and emphasize the subject of the course rather than grammar and spelling. The Physics Department's response to this charge was the "Writing in Physics" course (Mullin, 1989). In the "Writing in Physics" paper, Mullin (1989) mentioned the number of ways in which the "Writing in Physics" course has helped their students without providing any quantitative or qualitative proof of the actual effectiveness:

> "[T]he content and style of their technical writing has improved; they write with more confidence; they have learned something of organizing and revising their writing; they have been made aware that physics is highly dependent on intuitive arguments; they have learned that there are many writing styles in this discipline and that they are likely to encounter several in their careers; and they have learned some aspects of contemporary physics research that they would not have seen without this course." (p.342).

Again, without any other evidence but based solely on his observations, he claimed that writing improved students' learning and that the "Writing in Physics" course created interactions between students and members of the university's writing program. The primary goal of the "Writing in Physics" course was writing and so Mullin designed activities that required critiquing from instructors and fellow students. He believed that revision is a key to improving writing and increasing confidence in writing. Reading assignments of articles by good writers in the subject area as well as preparing essays with instructor feedback, revision, and peer review were included in this course. For instance, the topic of an essay was "Write an essay explaining to a freshman Physics 141 student why an airplane flies" or another assignment was based on William Irvine's talk on Halley's comet (Schloerb et al., 1986). Some assignments dealt with the philosophy, methodology, ethics, or history of physics or astronomy. "Freshman Seminars" were the main part of this course in which faculty described the frontiers of physics by describing their research in elementary terms and students were then given a writing assignment based on the talk. Mullin hoped these seminars would bring the students up-to-date and preparing assignments about the talks would introduce the students to qualitative or heuristic arguments in physics.

After offering a successful junior-level writing course in physics department, Mullin was motivated to use writing in the traditional electricity and magnetism course at the junior level. In the electricity and magnetism course, Mullin (1989) designed essay questions and asked students to prepare a three to four page essay to explain the concepts without equations. This is an example of an essay assignment in the 'Electricity and Magnetism' course: "Explain the basis of the operation of the betatron. Make sure to relate your discussion to the principles of induction presented in the course" (p. 346). Mullin has not assessed any statistical data or conducted any interviews, but based on his own experiences and reading the students' writing products he believed that qualitative understanding of the physics concepts help students in solving problems and writing is a valuable tool to reach this goal by encouraging heuristic thinking and learning (Mullin, 1989).

1.5.2.2 Dr. Teresa L. Larkin. Dr. Teresa L. Larkin is an associate professor of Physics Education in the Department of Physics at American University. She has worked on writing in physics for a long time and has many publications in this field (Hein [Hein is Larkin] 1999; Larkin, 2000; Larkin & Budny, 2001; Joyner & Larkin, 2002). Her publications describe courses in which she has emphasized the use of writing. They linked two introductory general education

Liberal Arts courses in American University: an introductory physics course for non-majors and an introductory college writing class. Students were given writing assignments in the college writing class about the materials covered in the physics class. Larkin and Joyner used these writing assignments to study the linking of these two courses and one year later she used the Force Concept Inventory (FCI) survey to measure students' understanding of concepts in basic mechanics. The variety of assignments used in the linked courses is interesting to me. For instance one assignment asked students to assume they'd been involved in a car accident with a Mitsubishi Spider and two other vehicles. They were to explain the collisions in terms of momentum and energy. The assignment asked them to build a narrative around the accident, inventing characters and point of view. Most importantly, students had to present an explanation of the physical concepts of the collision in plain language to a supposed friend (who happened to be driving one of the vehicles) who knows very little about physics (Joyner & Larkin, 2002).

The linked courses involved various kinds of writing assignments such as preparing a report of an event observed on campus, doing research on a physics topic and make a report similar to the journal papers, and analyzing one of the course texts with interpretation of an element of one or more of the texts.

Larkin's publications are more about introducing a writing activity in physics classes than addressing the research questions proposed. Larkin talked about the comments left by students in her publications, but she neither conducted any qualitative research to find out what students think about writing in physics nor any quantitative analysis to support her claims. For instance in the publication called "Writing and Physics: an Interdisciplinary Approach" (Joyner & Larkin, 2002) it is claimed, "This study showed that when writing was used as an assessment of student learning, the window into students' understanding became clearer. Instruments such as the FCI are just one aspect of assessment and evaluation. Thus, the FCI data is offered here as a supplement to the assessment of student learning via the writing activities” and “The use of writing in introductory physics classes for non-majors may help students develop their critical thinking and problem-solving skills. In addition, writing can help them identify and confront their misconceptions about a specific topic in physics” (Joyner &Larkin, 2001, P. 5). However, there is no analysis showing how writing made students’ understanding clearer and helped them confront their misconceptions. To support her claim about confronting misconceptions, she referenced her own articles that don’t provide any explanation how she came to this decision.

A number of her publications start with strong statements such as “Writing can serve as a tool to improve the quality of teaching as well as to promote deeper and more meaningful student learning” (Larkin & Budny, 2001, p. 22), although she provides no research or data to support those assertions except for her own interpretation of the students’ writing products. Larkin has collaborated with people at the University of Pittsburgh to use writing in a second year engineering course (2001). Her activities with the designed writing assignments seem interesting to me. She reads the weekly writing assignments and provides detailed feedback. Larkin modifies her lectures based on problems she observes in the writing assignments, which has the great benefit of formative assessment.

1.5.2.3 Larry Kirkpatrick. Dr. Larry Kirkpatrick is a professor in the Department of Physics at Montana State University. He has observed that many students who get A’s in physics courses are unable to explain relationships among various physics concepts. Kirkpatrick believed that “a student who understands a relationship should be able to write a clear, concise essay applying the relationship to specific situations” (Kirkpatrick & Pittendrigh, 1984, p.159). He thought that such an essay should be logical in its construction and clear in its meaning and so “the essays must be graded on the basis of the clarity and style of writing as well as the clarity of the physics” (1984, p. 159). Even if the presence of an English teacher may seem unusual in the physics classroom, Kirkpatrick believed that this can improve the physics learning.

He had instructor from the English department present in his classroom in Montana State University to help him conduct the weekly writing assignments and improve the quality of student writing. Before this project he used essay questions as a testing device to find out whether students really understood the concepts presented in the course. He expected his students to be able to manipulate concepts and laws to explain unfamiliar phenomena if they really understood them. However, students’ essay answers were unclear and it was hard to tell whether the student was having trouble with the physics or the writing. Therefore, he decided to explore whether collaboration between physics teachers and writing teachers could help students enhance the quality of their essays. Kirkpatrick gave a template for writing called “RAFT,” which defined the Role, Audience, Format, and Task. He believed that students often have trouble writing an essay when they don’t know their role and their audience. He told students that they should write their essays as a peer tutor with the task of communicating a clear chain of reasoning to another student who understands most of the material presented in the course, but for some reason cannot answer the particular essay question. He also presented students with a format to help them in thinking and writing in an ordinary way: key ideas, general ideas, specific cases, and frosting (optional additional insights). Finally, he devoted a class hour to discussion of an essay and asked students to write an essay answer in the class. Students received feedback in the class and discussed the ideas and possible ways of answering the essay questions. Based on students’ performance on the essay exams, Kirkpatrick believed that writing and having an English expert in the class are beneficial to the students, but he never collected any data from his class or conducted any interviews to explore students' perspectives. His philosophy was "if teachers believe a skill is important, it must be explicitly included in the course. That is, not only must the skill be taught, but it must also be tested and the results included in the tabulation of the grade" (1984, p. 159). He continued to use writing assignments in his classrooms up until his retirement and he always believed that "the presence of an English teacher – either physically or in spirit – can improve the physics learning that takes place" (1984, p. 159). He provided several remarks based on his classroom observations and the students' performance on the writing assignments. For instance he observed that even if many of his students were initially reluctant to write, the quality of their writing improved significantly with the inclusion of the English lecturer. He found the students' answers more comprehensive and believed that there were less disconnected answers and more logical relationships among various concepts. In addition, the essays became easier to read by the end of the semester and as a result it became easier to see whether students understood physics concepts or not. Based on the comments left by his students, the most difficult part of writing was 'understanding the physics' and once they understood the physics it was easier to write down their ideas on the paper. Even if many students were not a fan of writing at the beginning of the course, their attitudes toward writing improved by the end of the semester and they believed that writing helped them think and improve their understanding of the materials.

1.5.2.4 Scott Franklin and Lisa Hermsen. Lisa Hermsen is a professor in the Department of English and Scott Franklin is a professor in the School of Physics and Astronomy at the Rochester Institute of Technology (RIT). Similar to Kirkpatrick, they have combined essay writing in introductory physics classes with English instruction. Having both physics and English instructors in an introductory physics course has also been studied in Ohio State University (Demaree, 2006).

Hermsen and Franklin developed some methods to analyze students' writing products: 1) primary trait scoring, 2) revision-based analysis, and 3) key stroke analysis. These assessment strategies are used to analyze the exchange & structure, expression & arrangement, and understanding of information. Primary Trait Analysis (PTA) is a procedure to categorize the assignment-specific observable traits in written documents. "PTA establishes learning outcomes as criteria for assignment-based assessment. Identified criteria may be assignment-specific or consistent throughout a class" (Hermsen & Franklin, 2006).

Franklin and Hermsen (2006) graphed the frequency of sentences coded as motivation, procedure, observation, inference, or fact. They found that more sophisticated writers have more presumption and exploratory sentences, and less sophisticated writers use "procedure-observation" sentences such as "we did this and saw this."

Revision-based assessment is regarded as a central part of the writing process by Franklin and Hermsen because it enhances the final written document and it requires students to rework ideas and as a result it potentially enhances learning (Flower & Hayes, 1981; Hermsen & Franklin, 2006). Franklin and Hermsen used Microsoft Word's "Track Changes" to determine the revisions students make while providing their writing activities. Students were supposed to prepare two drafts: draft 1 with a 250 word limit, and draft 2 that must be no more than 125. This encouraged the students to revise their writing assignments. The revisions were classified into two main categories: content-based revisions and language-based revisions. There were some methods developed (on a computer) to capture each keystroke, as an essay was prepared. These tools highlighted the order of revisions (Hermsen & Franklin, 2006).

Students were required to submit weekly essays at the level of a typical Scientific American article. Students were supposed to revise their weekly activities and integrate them into one seamless essay. During the quarter, students completed three separate essays. Each essay was revised 3 to 4 times. Students were given an assessment of their writing ability as well as comments on the extent of the revisions. They were also given some writing samples that contained both positive and negative comments. Franklin and Hermsen's work used the methods of primary trait analysis, revision-based assessments and key-stroke analysis to establish a connection between writing and learning. However, their assessments were based on the students' writing essays and they did not conduct any qualitative research to explore their students' perspectives on writing essays and the analysis methods used.

1.5.2.5 Calvin S. Kalman. Dr. Calvin Kalman is a professor in the Department of Physics at Concordia University. Dr Kalman has developed various activities to create a student-centered environment in the class in order to give students an opportunity to explore physics concepts. I will provide a summary of activities developed by Dr. Kalman and will explain how my research is related to the work done by Dr. Kalman's group.

Dr. Kalman emphasized critical thinking in writing and believed that critical thinking is goal directed and involves reasoning (Kalman, 2006). The main motivation behind the activities developed by him is to encourage students to think critically. Dr Kalman (2006) believed that students need to test their views to develop their critical thinking skills. He developed an activity called 'reflective writing' in which students read the textbook and write their own understanding of the concepts before each class. An introduction to this activity is provided in Section 1.3. Dr. Kalman's use of writing prior to engagement in the classroom has many parallels with my project. Kalman and his research group (Huang & Kalman, 2012; Kalman et al., 1999) have tested reflective writing in conjunction with other activities as we are testing it in conjunction with labatorials in MRU. Physics lab instructors in MRU provide a list of textbook sections related to each experiment and ask students to write their own understanding of the concepts and hand in their writing products three days before each lab. Kalman believed that speaking to others is a helpful way of achieving a better understanding. The main motivation behind the reflective writing activity is to give students an opportunity to construct a self-dialogue about the concepts in the textbook (Huang & Kalman, 2012; Kalman 2006). Huang and Kalman (2012) believed that in summary writing students write down what they have in their mind during their reading, while in reflective writing students are expected to question what they have read and relate it to other concepts. Each week students are asked to produce reflective writing about the concepts that will be covered in the next lecture (2012).

In MRU, we are using the rubric developed by Kalman, Milner-Bolotin, Antimirova, Aulls, Charles, Huang, Ibrahim, Lee & Wang (2012) for marking reflective writing products (see Appendix A for the reflective writing rubric developed by Kalman et al.). Normally students should be provided with the rubric at the beginning of the course to help them understand how they should go about doing reflective writing. Although there is an instruction provided for students to do reflective writing assignments, we are not sure whether they follow the instruction or they use their own techniques to provide the writing assignments.

As mentioned earlier, Kalman and his research group have found that reflective writing activity is a helpful activity (Huang & Kalman, 2012; Kalman, 2011; Kalman & Rohar, 2010; Kalman et al., 2008). They have studied reflective writing in conjunction with other activities, as this thesis studies it in conjunction with labatorials. Therefore, a brief overview of Kalman's studies is presented here. Kalman, Morris, Cottin and Gordon (1999) developed and tested a collaborative group learning approach on four concepts by comparing two sections taught by the same professor. They used the force concept inventory (FCI) as a pre- and post-test. In one section they used collaborative learning approach to teach the concepts, while in the other section a standard professor-centered approach was taken. To compare the two sections, they designed three questions of the same type and style as the force concept inventory (FCI) and added them to the FCI pre- and post-tests as questions 30, 31, and 32. The results showed a gain for the section using collaborative learning over the control group. Since their long-term goal was to “bring as many students as possible to the highest level of critical thinking” they believed that the collaborative group sessions must be fleshed out with other student-centered activities such as writing exercises (1999). The collaborative group conceptual exercises followed by writing a critique as homework was performed and tested by Kalman, Rohar, and Wells (2004). They assessed the FCI pre- and post-tests results and found that the addition of the critique activity resulted in a statistically significant improvement in comparison with the use of collaborative group exercises alone (2004).

The studies on Reflective Writing involve qualitative analysis (Kalman, Aulls, Rohar & Godley, 2008, Huang & Kalman, 2012). The qualitative study done by Kalman, Aullus, Rohar and Godley (2008) contained a survey, as well as semi-structured interviews to explore the students’ perceptions on reflective writing. Their publication (Kalman et al. 2008) provided a detailed introduction to this activity. However, the survey and interview questions did not provide details about students’ perspectives and how they found reflective writing helpful. For instance there is a student’s statement about understanding the physics equations, but there is no detail to find out how reflective writing helped this student to make sense of the formulas in the textbook: “I see in my writing a lot where I don’t understand a formula and then eventually it will make sense” (2008, p.79).

Huang and Kalman (2012) conducted a multiple case study in two science courses to find out whether there is any relationship between the students’ performance in reflective writing and their views on the nature of knowledge and learning in physics and science. They developed a Likert scale questionnaire and administered the survey in two institutions. They found that students with higher scores on the survey had more writing assignments indicating reflective writing (2012). Their finding is consistent with my own experience using reflective writing in labatorials. In labatorials we ask student to make predictions and after performing the experiments they discuss whether the results support their hypothesis or not. Students who rely on authority or a textbook to gain knowledge make predictions based on what their instructor said in the class or what they read in the textbook. Their expectations influence their observations and they perform experiments with the internal goal to prove what was taught in the class or what they read in the textbook. These students’ conclusions are thus frequently unrelated to the results of the experiments. Based on my own experience and observations, such students’ writing assignments contain a summary of the concepts explained in the textbook and lack reasoning and critical thinking. This is consistent with what Huang and Kalman (2012) found about the correlation between students’ epistemology on science and their performance in writing assignments. Kalman (2009) has always emphasized the importance of epistemology in teaching and learning and there has been qualitative research done by his group. Huang and Kalman (2012) interviewed students in a calculus-based Mechanics course. There were two sections taught by the same instructor. They chose one section as their experimental group doing reflective writing assignments on chapters, group activities followed by critique and write-pair-share. The other section acted as their control group only doing summary writing on chapters. This qualitative analysis showed that it is possible for students to change their ways of learning because of implementation of these activities in one semester, but there was no evidence for change of their personal epistemology through one semester. There is no research done to explore whether using reflective writing in labatorials changes students' epistemology and their ways of learning. This motivated me to design a quantitative analysis with experimental and control groups. The results are presented in Chapter 9. The main research questions addressed by Kalman's group were whether students approached the textbook in the manner of hermeneutics and whether their epistemology changed during the semester. No research work has focused on the ways students find reflective writing helpful. This is an important issue that helps instructors know more about students' ways of learning and how reflective writing is helpful at achieving effective students learning outcomes. My findings and results related to this issue are presented in Chapter 7.

1.6 Research Contribution to the Literature Review

The bottom line from the literature review is that there are no conclusive and systematic qualitative or quantitative studies to show how writing in physics helps learning. In the published studies on the use of writing in physics classes, there is little research-based evidence to show whether they aid learning within the disciplines. As discussed in the previous section, Mullin, Larkin, Kirkpatrick, Franklin and Hermsen all discussed innovative uses of writing in the classroom. They all stated that writing in physics is beneficial without providing reliable evidence for their statements or explaining how the writing activities used helped their students. Therefore, we do not truly know if those writing activities were successful since there is usually no supporting evidence for the concluding reports made. In addition, if they really were helpful, we do not know the reasons or the specific characteristics of the activities that make them successful. That is why besides introducing a new writing activity in introductory physics courses in MRU, the primary purpose of this project is to find out how reflective writing activity helped students during the semester.

The qualitative studies done by Kalman's group have focused on whether students approach the text in the manner of hermeneutics and whether using reflective writing with collaborative group activities can change students' epistemology. It is of great importance to study students' perspectives on using reflective writing to find out how reflective writing helps students and changes their ways of learning. The results of this project can contribute to the debate on whether there is merit to the common viewpoints and claims about writing. There is an ongoing collaboration among the Chemistry and Physics Department in Mount Royal University and the Physics Department at Concordia University and the Department of Physics and Astronomy at the University of Calgary to study the value of reflective writing in introductory physics courses and labs. This is our long-term goal, to find out how reflective writing helps students in introductory physics courses and changes their ways of learning. The results of the qualitative case studies conducted by Kalman's group in Concordia University and some other institutions in Canada (Huang and Kalman, 2012) support the fact that reflective writing is helpful. To find out how this activity is helpful is the primary objective of this research project. Since we are using reflective writing in introductory physics labatorials, it is our secondary goal to explore students' perspectives on labatorials to investigate how they find labatorials helpful.

As discussed in Section 1.2, based on the studies done by Kalman's research group on reflective writing activity (Huang & Kalman, 2012; Kalman, 2011; Kalman & Rohar, 2010; Kalman et al., 2008) and the pilot study conducted in fall 2013, we hypothesized that reflective writing encourages a hermeneutical approach to science, improves students learning strategies, and in combination with another interactive intervention can change students' epistemological beliefs. A hermeneutical approach to science helps students gain a better understanding of concepts (Borda, 2007). This can shed light on how reflective writing is helpful if we find that this activity provides an opportunity for students to approach the text in the manner of hermeneutics. A brief history of hermeneutics and its application in science and education is provided in Chapter 2. A hermeneutic approach to science necessitates attention to the development of dispositions such as doubt, humility, and strength (Borda, 2007). For instance the doubt disposition means that students must be willing and able to identify and question their pre-knowledge and also doubt any new understanding they gain through questioning. It is important to have humility, which means students never think that they always have the right answer as this belief would make gaining new understanding difficult (Borda, 2007). To gain such points of view requires helping students change their epistemology towards science and knowledge. An introduction to epistemology and its relationship with hermeneutics is presented in Chapter 3. In this thesis I also discuss the strategies that students take to prepare their writing products. It is of great interest to find out what they actually do to understand the concepts and what strategies they take to reflect their thoughts. This helps us improve the reflective writing instructions in future. The research questions and the methodologies to address the research questions are explained in Chapter 4.

Chapter 2: Hermeneutics

Martin Packer (2010) suggested that using interviews as a tool in qualitative research requires asking some crucial questions such as: What is the relationship between a text and its author? How do we interpret statements? How do we understand the meaning of a text? These questions have been asked for hundreds of years and have been addressed in the field known as hermeneutics. Hermeneutics is the theory of interpretation (Howell, 2012; Packer, 2010). The name hermeneutics comes from "Hermes," messenger and interpreter of the Greek gods. Hermeneutics blossomed in the 17th century as a way of interpreting the Bible and other ancient texts (Packer, 2010; Howell, 2012). These texts were written a long time ago in a culture very different from modern culture and so they were far from the contexts of their original creation and as a result understanding "the word of God" was becoming increasingly difficult (Packer 2010). The term "hermeneutics" referred to a method used to understand these religious texts. Eventually hermeneutics expanded to a method used to interpret secular texts, cultural experiences, and indeed all forms of phenomena and human activity (Packer, 2010). Gadamer claimed that we do not need a methodology to acquire knowledge, but knowledge has to be acquired (Gadamer, 2013). The heart of hermeneutics is about understanding the knowledge that has been acquired. Gadamer believed that hermeneutics offers a way to know and understand the world by living life and being a part of the event, which means the researcher is not considered a separate entity but is a part of what he or she is researching (Annells, 1996; Packer, 2010). In this research work we are using interviews and analyzing students' writing products to investigate the usefulness of a hermeneutic approach to studying introductory physics textbooks. In this chapter I first briefly present the history of hermeneutics and then discuss hermeneutics in science and science education. I will explain how to apply hermeneutics to science education and how applying Gadamer's ideas of education can change students' epistemology. Epistemology will be discussed further in Chapter 3.

2.1 A Brief History of Hermeneutics

Modern Hermeneutics arose from the work of many philosophers over hundreds of years. Since the history and evolution of hermeneutics have been described elsewhere in detail (e.g., Palmer, 1999), here I only briefly present the approaches from some of the most influential hermeneutic scholars.

2.1.1 Friedrich Schleiermacher (1768-1834). I begin with Friedrich Schleiermacher (1768-1834), one of the first people who discussed the need for a secular, general, and universal hermeneutics. Schleiermacher believed that hermeneutics deals with the interpretation of all forms of discourse both written and spoken (Packer, 2010). He argued that this general hermeneutics is a systematic approach to interpretation and that the questions and issues, which come up when we read a text, also exist in everyday conversation or when we listen to someone talking. This secular hermeneutics employs the skills of interpretation that work within all cases of understanding. Schleiermacher was the first person to define hermeneutics as the study of interpretation in general, beyond the fields of law, religion, or aesthetics (Howell, 2012; Packer, 2010). He considered speech and writing as an expression of someone's feelings and thoughts. Discourse in Schleiermacher's view has two origins: the author's creativity and the medium of language (Gadamer, 2013; Packer, 2010). One without the other means nothing. He believed that understanding is the attempt to recollect the author's thoughts and hermeneutics is the art of interpretation that will achieve this reconstruction (Packer 2010; Gadamer 2013). He believed in the recreation of both the language and the thoughts of the author. In other words, understanding in Schleiermacher's point of view includes "two elements – understanding the speech as it derives from the language and as it derives from the mind of the speaker" (cited in Packer, 2010, p. 85). Schleiermacher called these two elements "grammatical interpretation" and "psychological interpretation." The grammatical interpretation focuses on language with its grammar, components, and rules; in other words, the structure of language. The psychological interpretation focuses on the meaning the interpreter is trying to bring to the text (Gadamer, 2013; Howell, 2012; Packer, 2010). This side of interpretation that Schleiermacher called "subjective reconstruction" studies the link between discourse and its author's subjectivity, which intends "to understand the discourse just as well and even better than its creator" (cited in Packer, 2010, p. 86). Schleiermacher did not think that we could gain understanding naturally or easily. He believed that what follows automatically is misunderstanding and thus we must work continually to overcome it. "[M]isunderstanding follows automatically and understanding must be desired and sought at every point" (cited in Gadamer, 2013, p. 191). Schleiermacher introduced the concept of the hermeneutic circle. He believed that "every extraordinary thing can only be understood in the context of the general of which it is a part, and vice versa" (cited in Packer, 2010, p. 86). There are several related concepts of the hermeneutic circle. One involves the relationship between the parts and the whole in which understanding a text as a whole requires understanding its individual parts, but at the same time understanding each individual part requires understanding the whole text. A circular relationship can also exist between a text and its context. The relationship between reader and discourse is also a hermeneutic circle that never achieves a final conclusion. Heidegger (see Section 2.1.3) proposed a hermeneutic circle between understanding and interpretation (Gadamer, 2013; Packer, 2010).

Schleiermacher presented two methods of interpretation: the comparative and the divinatory. The comparative moment involves comparing the discourse with other texts created by the same author and the divinatory requires creativity of the interpreter to grasp the thoughts and creativity of the author. These two methods actually show the difficulties of reconstructing (Packer, 2010). “Using the divinatory [method], one seeks to understand the writer intimately to the point that one transforms oneself into the other” (cited in Packer, 2010, p. 88). Schleiermacher believed that there is a pre-existing connection among all people and this makes it possible for one to project oneself into the mind of the author. For him the purpose of interpretation included both understanding the text better than its author and knowing the author better than he did. This purpose of interpretation of a text seems impossible to achieve (Gadamer, 2013; Packer, 2010). Gadamer (see Section 2.1.4) believed that:

> “Reconstructing the conditions in which a work passed down to us from the past was originally constituted is undoubtedly an important aid to understanding it. But we may ask whether what we obtain is really the meaning of the work of art that we are looking for, and whether it is correct to see understanding as a second creation, the reproduction of the original production. Ultimately this view of hermeneutics is as nonsensical as all restitution and restoration of past life. Reconstructing the original circumstances, like all restoration, is a futile undertaking in view of the historicity of our being. What is reconstructed, a life brought back from the lost past, is not the original.” (Gadamer, 2013, p. 166).

2.1.2 Wilhelm Dilthey (1833-1911). Dilthey was a German philosopher who was influenced by Schleiermacher and like him saw hermeneutics as a general methodology. Dilthey broadened the application of hermeneutics. He believed that hermeneutics could be applied not only in written texts and discourse but also in cultural events and artifacts (Howell, 2013; Packer, 2010). In his point of view, hermeneutics is the “methodology of the understanding of the recorded expressions” (cited in Packer, 2010, p. 88). Dilthey is best known for the way he distinguished between the natural and human or social sciences. He excluded using natural science methodologies to study social phenomena. Dilthey believed that natural science methodologies explore cause and effect from the particular to the general, while the relationship between the parts and the whole is of great interest in social science. He believed that natural science rejects the living world, while social science embraces it (Howell, 2013). Packer (2010) and Howell (2012) believed that Dilthey considers human science to be established on everyday understanding and what he calls “lived experience” (Erlebnis). Dilthey exposed that when we try to understand society, culture, and history, we are part of these phenomena since we are already involved in the human world.

Following on from the work of Schleiermacher, Dilthey explained the hermeneutic circle as a continual interaction between the implicit and explicit, and between the particular and the whole. He “wished to understand ‘other’ through immersion within situations and minds while at the same time ensuring distinction between ‘other’ and the researcher” (cited in Howell, 2013, p. 155). He believed that the process of understanding is historical and our lived experience is temporal. Past and future shape our lived experiences and these historical experiences are the basis for all understanding (Gadamer 2013; Packer, 2010). Dilthey found Schleiermacher’s conception of understanding too limited. He believed that understanding is not just a contact between subjectivities – the mind of the author and the mind of the interpreter – but a reconstruction of the historical process that has formed a cultural phenomenon. For Dilthey, hermeneutics is the theory of how life reveals and expresses itself in cultural work. The objective interpretation is something that Dilthey cares about deeply. If we are thoroughly involved in history, it is difficult to gain an objective viewpoint on human phenomena and this was what Dilthey tried all his life to achieve (Packer, 2010; Palmer 1999). By pursuing a level of objectivity, Dilthey is criticized by many subjective-oriented scholars. For example Gadamer argued that Dilthey failed to extend beyond the methodological differences between social and natural sciences. He was insufficiently concerned with the ontological[5] event of truth, and did not consider how the interpreter and his or her interpretations are not outside of tradition, but occupy a position within it (Gadamer, 2013; Howell, 2012; Packer, 2010).

2.1.3 Martin Heidegger (1889-1976). Heidegger emphasized the meaning of "Being and Time" in interpretation and believed that since we are in the world there is no differentiation between research and researcher. Because the researcher is a part of the world there can be no distinction between subject and object (Howell, 2012; Packer, 2010). Heidegger was a student of Edmund Husserl. Husserl believed that it is necessary to block out the world outside and put aside one's own biases in order to gain understanding about a phenomenon. Heidegger argued that as human beings we are connected to the past, present and future and we are in the world before we reflect and this fact makes us both subject and object. He believed that pre-understanding cannot be set aside and bracketing the outer world cannot happen (Howell, 2012; Packer, 2010). Husserl proposed that one needed to bracket out the outer world as well as individual biases about the phenomena in order to see it clearly. Heidegger was against the process of suspending one's judgment or bracketing the outer world (Howell, 2012; Packer, 2010). Howell (2012) believed that Heidegger made an ontological[6] shift in hermeneutics by

[5] *Ontology* is the study or concern about the nature of being. Heidegger believed that hermeneutics is ontology as it is related to the most fundamental conditions of man's being in the world. Heidegger erased any distinction between the individual and experience, considering them as co-constituting each other. From this perspective, Heidegger saw bracketing as impossible since he believed that one cannot stand outside the pre-understandings and one's experiences.

addressing the notion of "Dasein", which means 'being in the world.' Heidegger's hermeneutics is ontological and is concerned with the fundamental conditions of individual's being in the world. For Heidegger, hermeneutics is not a way of understanding linguistic communications, nor a methodology for human sciences. In Heidegger's view, understanding is about being in the world (Dasein), which is a characteristic of human beings (Howell, 2012).

2.1.4 Hans-Georg Gadamer (1900-2002). Gadamer was a student of Heidegger, and expanded Heidegger's work in the region of pre-understanding, historicity, dialogue, the hermeneutic circle, and the theory of horizons. Gadamer criticized the views of Schleiermacher and Dilthey about reconstructing the creative act that originally produced a phenomenon. In such views hermeneutics reproduces an original production and Gadamer believed that what is reconstructed is not the original phenomenon. Gadamer claimed that it is impossible for one to get inside the mind and the life of the author to reconstruct what he created (Packer, 2010; Howell, 2012; Gadamer, 2013). Similar to Schleiermacher, Dilthey, and Heidegger, Gadamer believed that interpretation is grounded in understanding and both understanding and interpretation are practical. In his point of view, interpreting a text is the process of asking questions that come up from our own time and is about the experience that one has while reading it. Reading is not about understanding the author, but about understanding what they wrote about. Gadamer believed that "a person reading a text is himself part of the meaning he apprehends. He belongs to the text that he is reading" (Gadamer, 2013, p.349). In contrast to what Schleiermacher and Dilthey stated, in Gadamerian hermeneutics there is no single correct interpretation of a text. A true interpretation applies a text to address the questions that arise at the time one reads the text. Gadamer claimed that interpretation can never be free of preconceptions and prejudices since an interpreter is the product of a particular moment and place. He emphasized that these preconceptions and prejudices show our openness to the world and play a positive role in interpretation. Gadamer was strongly against attempting to eliminate preconceptions and believed that our prejudices set limits beyond which we cannot see, but they are not fixed and we are constantly testing and questioning them. They show our involvement in history and culture and it is impossible to put ourselves aside from our preconceptions. He never denied that some preconceptions are inappropriate and need to be changed. He believed that they are not fixed and we constantly question our preconceptions. Like Dilthey and Heidegger, Gadamer emphasized the location of an interpreter in history. Gadamer (2013) explained the term "horizon" as "the range of vision that includes everything that can be seen from a particular vantage point" (p. 313). Your horizon is all that you can see, which is defined by your preconceptions and it is impossible for someone to see everything. Gadamer believed that the observer's horizon arises from the observer's cultural background that is a product of an historical moment. In contrast to Schleiermacher and Dilthey, a distance from the past was never considered a problem by Gadamer. Gadamer argued that we cannot go back in time or place ourselves in the mind of a dead author and these facts are not problems in understanding a text written in the past. He believed that there is a tension between the text and the present and tradition makes a connection between present and past. An interpretation must bring out this tension and when this happens there is a fusion between the interpreter's own horizon and the horizon of the text (Gadamer, 2013; Packer, 2010). Gadamer believed that "this process of fusion is continually going on, for the old and new continually grow together to make something of living value, without either being explicitly distinguished from the other" (Gadamer, 2013, p. 317). Our horizon is something flexible into which we move and it also moves with us. When your horizon encounters the horizon of a text or another person, a new horizon is formed and new understanding is created. This fusion of horizons happens when you have interaction with texts, arts, people, and in general any kind of phenomenon (Gadamer, 2013; Howell, 2012; Packer, 2010).

2.2 Hermeneutics in science and science education

Hermeneutics was first involved as an art of understanding in social science. The role of language in understanding natural science, the historical characteristics, interpretation, and contextuality of scientific knowledge led to similar arguments in natural sciences as well. Therefore, the hermeneutics of natural science came out as a new research field (Eger, 1992; Fehér, 1999).

Eger (1992) believed that the most important problem for education is the problem of meaning. He is against the views of people such as Dilthey who believe in differentiating between social science and natural science. Some philosophers like Dilthey consider natural sciences as methodologies to explore cause and effect and believe that social sciences seek understanding of meaning (Packer, 2010). Eger (1992) argued that understanding of the meaning in science beyond its role in uncovering causal relationships is an important issue that must be considered in science education. Eger considered hermeneutics as “the reflection on how understanding of meaning comes about” (Eger, 1992, p. 338). Martin Eger's papers (1992, 1993) on hermeneutics, science and science education have helped shed light on the practice and learning of science in an interpretive frame. In Eger’s point of view, increasing numbers of students in science fail to see meaning in scientific ideas and concepts since they are not familiar with the language of science. Eger (1992) regarded science study as the interpretation of the language of science. He believed that interpretation is needed whenever a strange language is encountered and it demands hermeneutics whenever there is interpretation. What we face are not really the phenomena of nature themselves, but a range of written and spoken texts such as lectures, research reports and textbooks. Students don't encounter the book of nature in science courses, but the book of science which is written in a language that scientists use to talk about nature (Eger, 1992, 1993). Therefore, students can have great difficulty understanding scientific texts since the language and epistemology of science are not familiar to them (Kalman & Rohar, 2010). A hermeneutical approach to science provides an opportunity for students to gain a deeper understanding of the meaning in science (Eger 1992). In this section, I explain the importance of having a hermeneutical approach to science education and discuss the ways developed by Gadamer and Borda to implement such an approach in science courses. I will clarify how a reflective writing activity is developed to help students approach introductory physics textbooks in the manner of hermeneutics.

Eger (1992, 1993) related hermeneutics to science through language. He believed that to understand the language of science, it is not enough merely to learn the definitions of the terms, and go over a few examples of their use. Therefore, "there is an increasing demand for 'real world' experiences in education, an end to 'lecturing', and so on" (Eger, 1992, p. 341). Considering real world experiences avoids students looking upon science from the outside. Paying attention to real world experiences in education is parallel to the work of Heidegger and Gadamer who believed that understanding is about being in the world (Dasein), which is a characteristic of human beings. Providing examples related to real life experiences is one of the main marking criteria of reflective writing activities. This helps students avoid looking upon science from the outside.

Eger (1992, 1993) has used Gadamer's explanation of back-and-forth movements between the parts and the whole in a text to clarify the hermeneutical approach to science texts. To understand a text, it is necessary to know the meaning of the phrases and the meaning of each phrase depends on the paragraph and the whole text. On the other hand, to understand a text we must know the individual parts. When we encounter a text, we start with some preconceptions and projections. We use these preconceptions to make sense of the small parts of the text that require a sense of the whole text. There is a series of back-and-forth movements between the parts and the whole. Schleiermacher acknowledged that there is "an apparent circle" in interpretation so that understanding each part of a text requires considering the whole text and vise versa (Packer, 2010). Heidegger explained that the hermeneutical circle works between understanding and interpretation. Heidegger argued that understanding is the pre-reflective knowledge that we have of a text and interpretation is the expression of this understanding (Packer, 2010). Howell (2013) believed that Heidegger and Gadamer developed the hermeneutical circle based on pre-understanding and understanding. Gadamer (2013) believed that:

> "A person who is trying to understand a text is always projecting. He projects a meaning for the text as a whole as soon as some initial meaning emerges in the text. Again, the initial meaning emerges only because he is reading the text with particular expectations in regard to a certain meaning. Working out this fore-projection, which is constantly revised in terms of what emerges as he penetrates into the meaning, is understanding what is there." (p. 279).

As discussed before, Gadamer presented the term "horizon" to clarify the role of fore-projections in understanding (Gadamer, 2013). The interpreter seeks a fusion between his/her own horizon and the horizon of the text (Packer, 2010). “This process of fusion is continually going on, for the old and new continually grow together to make something of living value, without either being explicitly distinguished from the other” (Gadamer, 2013, p. 317). In Schleiermacher’s conception of a hermeneutical circle, it is required to consider the individual parts to understand a text as a whole and at the same time understanding the individual parts requires a sense of the whole text (Packer, 2010). Heidegger and Gadamer explained the hermeneutical circle based on pre-understanding and understanding (Howell, 2013). Kalman (2011) believed that when students approach the textbook to provide their reflective writing assignments, they move between parts and the whole and also a hermeneutical circle operates between their pre-understanding and understanding. Students in introductory physics courses have some ideas about physical concepts, such as force, velocity, mass and so on. These ideas may come from their former educational experience, or from their own experiences. Students’ preconceptions and ideas make sense in explaining observations in their life and are reasonable to some extent. Therefore, when a student comes to a text, two horizons are in view: the horizon of the student (horizon A) and the horizon of the textbook (horizon B). Horizon A as a whole contains student's parts i.e. the students’ life experience, former theoretical knowledge, and the experience from the textbook. The textbook whole (horizon B) is a combination of its parts as well. If the two horizons overlap to some extent, students may use the overlap as a starting point to try to understand the text. The students’ horizons are dynamic and always open to change. For example, when students begin to learn Newton’s second law, their horizon A contains all those experiences and knowledge related to “force” or “motion.” A part of their horizon may overlap horizon B of the textbook. From this starting point, they project the whole, Newton’s second law, and then go back to check if the parts (their experiences and knowledge related to force and motion) add up to support the whole. If not, they may try to correct their understanding in reviewing the textbook again to create a new horizon (A), and then harmonize again the two horizons. This is the back-and-forth movement of the hermeneutical circle. In Figure 1, area "C" means that the students' understanding and the meaning found in the textbook overlapped in this area. But the rest of horizon A contains a mismatch. Students' process of understanding consists of constructing a new horizon instead of reconstructing the pre-existed meaning. Students are truly making their own understanding of what the textbook says. Consider overlap area "D" in Figure 1b. If this area is increased, it means that the students' horizon shifted towards the horizon projected by the textbook. Understanding is a process of fusion of the two horizons.

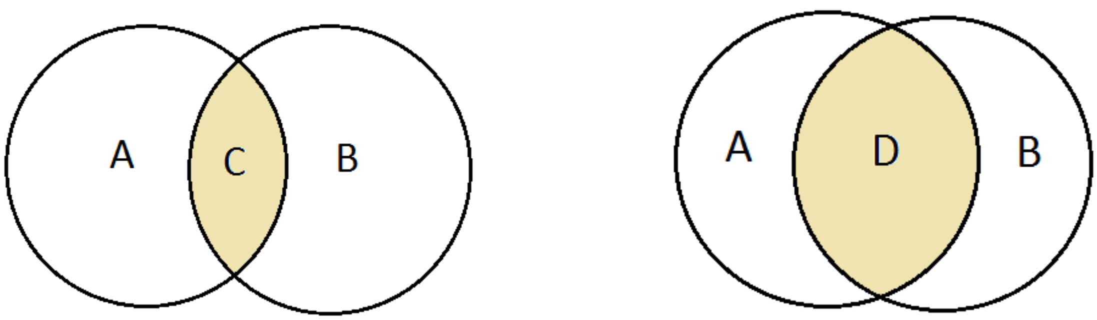


Fig.1a: Fusion after 1st pass

Fig1b: Fusion after 2nd pass

Figure 2.1: A schematic of the hermeneutical circle process

One of the purposes of using reflective writing in introductory physics labatorials is to encourage students to engage with the textbook and take an active part in their learning instead of being a passive receiver of knowledge. The back-and-forth movement between horizons A and B and also between the parts and the whole helps students to improve their critical thinking skills. Eger (1992, 1993) believed that critical thinking is fostered when we add questioning and communication into reading of a text. Halpern (2014) considered critical thinking as "the use of those skills or strategies that increase the probability of a desirable outcome. It is used to describe thinking that is purposeful, reasoned, and goal directed" (p. 4). Kalman (2011) also emphasized that critical thinking is goal directed since it focuses on a desired outcome – horizon B. Halpern (2014) believed that when we think critically, we actually evaluate the products of our thinking processes. Kalman (2011) also believed that when students experience a back-and-forth movement to find out whether their understanding is consistent with what they read, they are evaluating the outcomes of their thinking. Gadamer explained that openness to questioning preconceptions is the important part of a hermeneutical approach (Borda, 2006; Gadamer, 2013). The back-and-forth movement of interpretation is more than the replacement of a body of terms by other groups of words without thinking about their meaning. The back-and-forth movement involves comparison and thinking to make sense of the ideas and concepts in the textbook (Eger, 1993). This is possible when a student identifies and questions his preconceptions as well as the new materials presented to him and makes comparisons. In the next section I talk about some possible ways that help students foster a hermeneutical approach to science education. I also discuss the relationship between hermeneutics and epistemology.

2.3 The Relationship between Hermeneutics and Epistemology

I am not following hermeneutics as a research methodology (a qualitative methodology with particular forms of data collection and interpretation) in this study. My hypothesis is that reflective writing encourages a hermeneutical approach to science and similar to Eger (1992) and Borda (2006). I believe that a hermeneutical approach to science helps students get a better conceptual understanding of the materials presented to them. In Gadamer's point of view a hermeneutical science student must have hermeneutical consciousness to be able to identify and question his preconceptions. Gadamer believed that education is a process of self-formation and thus requires both immersion in research and dialogue with peers and teachers. Such an education can provide opportunities for students to foster a hermeneutic consciousness (Borda, 2006; Gadamer, 2013). Borda (2006) used the term “disposition” to explain hermeneutical consciousness in science education and defined it as “a consciously formed state or habit of mind” (p. 1029). Borda used Gadamer’s philosophical hermeneutics to discuss the dispositions that develop a hermeneutical approach to science education.

Gadamer (2013) explained that “absent-mindedness” is an important disposition for a hermeneutical scientist, which means enthusiasm and dedication to the topic of study. Borda (2006) believed that such involvement in the topic is similar to what John Dewey called “single-mindedness” which means complete interest in the topic. One way of creating interest in science students is to make a relationship between the theoretical concepts presented in the course and real world situations (Eger, 1992). In the reflective writing activity, students are required to provide examples related to their own experiences. This leads students to broaden their horizon and helps them see the topic of study from new perspectives (Borda, 2006). All students that we interviewed appreciated the fact that both labatorials and reflective writing activities emphasized the application of physics concepts in real life. They believed that this made the Phys1201[7] course interesting and easier to understand. Thinking about the application of physics concepts in real life also helps students explore the relationship among various physics concepts. For example, in the textbook it is explained that if an object is moving and there is no net force acting on it, it will continue moving in a straight line at a constant speed. It is difficult for many students to make sense of this statement; however it is simplified when you ask them to think

[7] Phys1201 is a 13-week course at Mount Royal University that provides an introduction to Newtonian mechanics. The topics covered include: vectors, motion in one and two dimensions including projectile motion, circular motion, forces, work and energy, impulse and momentum, and collisions.

about a puck sliding on the smooth surface of a frozen lake. This example can also help student to make sense of the Newton's second law, which explains that an object subjected to a net force will undergo an acceleration. If the acceleration of a puck sliding on a frozen lake is zero, the net force acting on the puck is zero. This explains the case of a puck sliding on a rough surface which experiences the force of friction and so the net force acting on the object is not zero. A simple example related to real life can help a student relate various physics concepts and make sense of the statements presented in the textbook. This also helps students change their views of science from a body of settled facts not related to each other to a field of interrelated concepts that are used to explain the phenomena that happen around us.

Another disposition emphasized by Gadamer is doubt. Having doubt means that a hermeneutical science student must have a sense of willingness to identify and question his pre-conceptions and also doubt any new understanding that he gets through such questioning (Borda, 2006; Gadamer, 2013). Doubt disposition doesn't mean a hermeneutic scientist must have a sense of insecurity but rather that he must be prepared and able to identify and question his preconceptions. He must also doubt any new understanding he has gained through such questioning. To improve this disposition in our students we ask them to identify the conflicts between the textbook and their own ideas while providing their reflective writing assignments. We don't want them to set aside their ideas and accept what they see in the textbook, but rather we want them to doubt both their preconceptions and what they see in the textbook and use reasoning to address any conflict that they encounter. Most first year students believe that what they read in the textbook and what is taught in the classroom is true and as a result they don't question the materials presented to them. A hermeneutical approach to science encourages students to question what is presented to them and moves them from receiving knowledge to constructing their own understanding. This helps students change their views of science from a body of settled facts to an explanation-building venture (Borda, 2006). Therefore, a hermeneutical approach to science can change students' epistemology over time. Gadamer (2013) argued that we need to be aware of our limitations while we question our preconceptions and the knowledge presented to us. In introductory physics labatorials students are required to identify the limitations and discuss the experimental results based on them. Therefore, humility is the third disposition, which means that a hermeneutical scientist is aware of his limitations and never thinks that he has the answer. It is important to presume that another party's view has pieces of truth that can be added to our understanding.

While hermeneutical science students try to see nuggets of truth in others' views they must also avoid losing their own views. Borda (2006) called this disposition "strength" and emphasized that this disposition plays an important role in hermeneutics. Kalman (2006, 2011) also believed that it is important for students to question both their preconceptions and what they see in the textbook. They should not forget their old beliefs and accept the ideas presented in the textbook. To foster questioning preconceptions (doubt) and having an awareness of the limitations of science (humility), teachers must carefully examine their use of language when teaching science lessons (Borda, 2006). Borda (2006) discussed a study, which found that teachers use more settled language with students than among their colleagues and the scientific world that they present to their students is less hypothetical and negotiatory. Teachers are expected to use more negotiatory language in science classrooms than a settled language. For example, it is important to say "these data suggest" instead of "the theory was proven" (Borda, 2006). Since many textbooks present knowledge as settled facts, it is important to provide an opportunity for students to negotiate the meaning of concepts and represent scientific knowledge as more tentative than settled. On the other hand, students should be taught not to present science as a body of settled facts in their writing products (Borda, 2006). Lemke (1990) believed that using abstract nouns and passive verbs represents science as more solid and authoritative than it really is. Encouraging students to write in first person is a simple solution that also improves the dispositions of “doubt” and “humility” in students and changes their personal epistemologies of science. In the reflective writing activity, we encourage students to write down their own understanding of the ideas presented in the textbook. Writing in first person is one of the marking criteria in reflective writing assignments. The most important role of hermeneutics in science education is to change students’ views of science as the only or the most legitimate form of knowledge to one basic way of talking about the world among many others. Therefore, a hermeneutical approach to science can change students’ epistemology in science and education. Borda (2006) believed that it is important to provide an opportunity for students to experience the theories and design investigations to address particular questions and attach meaning to the data gained. In some labatorials we ask students to make predictions and design an experiment to investigate a question. Such labatorials help students experience the difficulties of interpreting data and observations as well as the limitations of science. Therefore, it is of great interest to find out whether the combinations of reflective writing and labatorials can change students’ epistemology during the semester. Change in students’ personal epistemology can be a potential answer to the research questions (“how is reflective writing helpful at achieving effective students learning outcomes?” and “how are labatorials helpful in introductory physics courses in MRU?”). I provide an introduction to epistemology in Chapter 3. The epistemological survey used in this project is discussed in Chapter 4 and the results of the survey are presented in Chapter 9.

Chapter 3: Epistemology

3.1 The Importance of Epistemology in This Project

From the last chapter, we have seen that hermeneutics is a general way for people to approach new concepts in both social and natural sciences. A hermeneutical approach to science helps students construct their own understanding through reasoning. In the last chapter we discussed that questioning the knowledge presented and also questioning preconceptions happens through a hermeneutical circle when students go back-and-forth between horizon A (student's horizon) and B (the horizon projected by the textbook and/or the instructor). Checking for consistency between these two horizons develops scientific thinking and reasoning skills in students (Eger, 1993; Kalman 2006). Our primary motivation for the use of reflective writing and introductory physics labatorials in MRU was to help students develop a hermeneutical approach to science and become constructor of knowledge. In this project we want to find out how reflective writing and labatorials are helpful learning activities.

A hermeneutical approach to science encourages students to question their preconceptions and the knowledge presented to them in the classroom and textbooks. Those who think that knowledge in science is a body of settled facts that comes from authority take a passive role in learning and become a receiver of knowledge, while those who consider knowledge tentative and evolving are more likely to question their preconceptions and the knowledge presented to them and as a result are more likely to develop effective reasoning and critical thinking skills (Arons, 1990; Borda, 2006; Connolly, 1989; Eger, 1993, 1993; Kalman, 2006). It is through the development of these skills, in combination with engagement in the topic that yields true understanding and effective learning. To enable students to utilize a hermeneutical approach to science, as teachers we need to develop activities to foster the dispositions of “absent-mindedness”, “doubt”, “humility”, and “strength” in the classroom. Developing these dispositions is embedded within a broader conception of epistemology. Understanding whether or not the combination of reflective writing and labatorials can influence the students’ beliefs of knowledge and learning helps us address our research questions. Therefore, it is of great interest to find out whether there is a difference in the epistemological beliefs of the students who provided reflective writing products during the semester. Epistemology is a field of philosophy related to how individuals come to know, and their beliefs about knowledge and knowing (Hofer, 2000). Richard Fumerton (2009) argued that epistemological questions involve “the concepts of knowledge, evidence, reasons or believing, justification, probability, what one ought to believe, and any other concepts that can only be understood through one or more of the above.” (p. 1). Fumerton (2009) believed that there is no specific definition of epistemology, since not all epistemological researchers include, for example justification, as a definitive epistemological concept. I will discuss various epistemological models in this chapter and will explain the convergence points among them.

Students’ epistemological beliefs are an important area for educational research since they help us explore how students make meaning and how this can affect their learning. The studies (Garrett-Ingram, 1997; Schommer, 1990, 1993; Schommer, Crouse, & Rhodes, 1992) done in this area suggest that students’ epistemology can influence their understanding, conceptions, study strategies, and academic performance. A review of studies done in this field motivated me to find out whether the combination of reflective writing and labatorials changes students’ epistemological beliefs over the course of an introductory physics course. In order to explore this issue it is important to examine the epistemological models developed by epistemological theorists. Hofer (2000) believed that almost all the existing psychological works on epistemology are related to the work done by Perry (1999). As explained in Chapter 1, Perry (1999) believed that students move from a level of dualism (the acceptable versus the unacceptable, or the correct versus the incorrect) to a multiplicity level (all options in a particular situation are equally valid) and then to a relativistic level (knowledge is contextual and uncertain). There is not sufficient evidence of the final stage (i.e., commitment, see Section 1.1) presented by Perry (1999) among college students (using evidence and logic to make an informed choice among a variety of options and to make a dedication to action). It is up to us as teachers to help students move from a dualistic conception of knowledge to a multiplicity level so that they will question their preconceptions. Based upon Gadamer's ideas it follows that a hermeneutical science student must be willing and able to identify and question the student's preconceptions and also doubt any new knowledge presented to the student. Gadamer believed that we must be sufficiently aware of our limitations and assume that there are pieces of truth in another party's view that can be added to our understanding (Borda, 2006; Gadamer, 2013). The main purpose of using reflective writing is to provide students with an opportunity to question their ideas and discuss the conflicts between their understanding and what they see in the textbook. Similarly, labatorials give students the opportunity to question their preconceptions and establish a dialogue with each other through group activities and with lab instructors. Each labatorial worksheet starts with conceptual questions and then asks students to make predictions. Students use their pre-understanding to make these predictions. After doing the experimental activity, students need to explain whether their results support their predictions or not. Comparing the observed results with students' predictions gives them an opportunity to question what they knew and what they have gained intellectually.

Based on the theoretical orientation of the researchers, various characteristics of personal epistemology may be defined (Hofer, 2000). Hofer and Pintrich (1999) believed that this is partly due to the lack of a coherent definition of personal epistemology. The purpose of this chapter is to present a brief summary of the developmental, cognitive, multidimensional, resource, domain specific, and integrated models of personal epistemology.

3.2 Epistemological Models

The various theoretical models of personal epistemology and the points of convergence among all these models will be discussed in this chapter. These epistemological models include developmental models, cognitive models, multi-dimensional models, resource models, domain specific models, and integrated models.

3.2.1 Developmental theories. In Chapter 1, I discussed the views of the developmental and educational psychologists who believed that young adults mature through a series of stages (Inhelder & Piaget, 1958; Perry, 1999). I went through the developmental sequences presented by Piaget as a pioneer developmental epistemologist and discussed the work of William Perry, who explicitly built on the foundation of Piaget's work. The longitudinal and cross sectional studies in this field (Baxter Magolda, 2004; Belenky, 1986; Perry, 1999; Stafford et al., 1976) show that young adults experience a progression in thinking through a sequence of stages in college and beyond. Although there are differences in describing each stage, all of the models describe a movement from considering knowledge as an absolute truth to the view of knowledge as contextual. However, studies have shown that students distinguish disciplinary differences in epistemological beliefs. For instance, some see knowledge in science as more certain and unchanging than in social sciences (Hofer, 2000). Eger (1992) believed that there are some facts in both social sciences and natural sciences that don't change, but the way we interpret these facts and the event related to them can be contextual. For example, it is a fact that Lincoln was the president of the United States and we cannot change this truth, but we can have different interpretations of his role as a president during the American Civil War. Therefore, as there might be more facts in natural science than in history and also more discussion and interpretation in social science classes than in natural science lectures, students might thus believe that knowledge in science is more certain and unchanging. Generally, various epistemological models explain that the students who consider knowledge as an absolute truth play the role of knowledge receivers, while the ones who see knowledge as contextual play a self-constructed role.

Perry's work on the stages of intellectual and ethical development was based on extensive longitudinal interviews with male students at a medium-sized private university during the 1950s and 60s. I discussed the positions presented by Perry (1999) in the first chapter. Perry (1999) believed that a student’s learning experiences and engagement is more related to his views of knowledge than his study skills and motivation. Since Perry’s model was based on male students’ interviews, it created motivation in many researchers to interview female students. To find out whether Perry’s model is applied equally to female subjects, Belenky (1986) studied the epistemological views of a broad sample of women including university students and social service clients. The focus of their study was on the interviewee’s conception of herself as someone who gains knowledge more than her ideas of knowledge. The result showed a developmental theory similar to what Perry presented using male students. This theory discussed a movement from absolutist thinking to relativistic thinking (Clinchy, 2002). Belenky (1986) discussed that in the stage of absolutist thinking a student considers herself as a receiver of knowledge, while she has a constructive view of knowledge at the relativistic thinking stage in which she understands her involvement in the learning process.

Baxter Magolda (2004) founded her studies on Perry (1999) and Belenky (1986). Baxter's work explored a general epistemological model for all genders. In a longitudinal study with a gender balanced sample of first year college students, Baxter Magolda (2004) was able to directly study gender differences in epistemological beliefs. The results showed a movement from absolute knowing to contextual knowing very similar to the transition presented by Perry (1970) that we discussed in Chapter 1. Baxter Magolda (2002) found that there are slight gender differences within early developmental stages that dissipate as students move to the higher stages. The results of her studies suggest that in general males and females experience the same basic developmental stages.

3.2.2 Cognitive theories. Cognitive theories were shaped from the developmental theories and as a result both theories share a common structure. In 1981, Patricia King and Karen Kitchener (1981, 1994, 2004) developed a model of reflective judgment that presents seven stages of reflective judgment based on the longitudinal studies using a large and diverse group of male and female students at large public universities. Cognitive models study students' reasoning processes when they encounter a problem (King & Kitchener, 2004; Kuhn & Weinstock, 2002). Cognitive models also describe a transition from absolutist to relativistic thinking in students' reasoning process. The studies done by these cognitive researchers focus entirely on cognitive processes and include structured interviews and paper-pencil evaluation tools as well as a set of standardized rating processes (King & Kitchener, 2004; Kuhn & Weinstock, 2002). King and Kitchener (2004) used ill-structured problems to study how the epistemological beliefs of students are related to the way they make judgments about controversial issues. They showed that there is a developmental progression in the answers and judgments provided to such problems. The interviews were designed to study the students' evaluation of conflicting claims on a given problem. King and Kitchener (2004) presented three levels to describe students' reasoning: pre-reflective, quasi-reflective, and reflective. The pre-reflective stages are consistent with absolute thinking and considering knowledge as certain. Students at this stage strongly rely on authority and believe that there are correct answers for all questions. In the stages of quasi-reflective, students recognize that knowledge is uncertain and constructed. They consider alternative answers to a question and think about different ways to address an issue. In the final stages of reflective thinking, students consider knowledge as contextual and are able to re-evaluate viewpoints when they encounter new information (King & Kitchener, 2004). In all the models discussed so far, students progress through a sequence of stages and their ways of acquiring knowledge change from being passive to being constructive. Their reasoning also moves from realist, where students are not able to distinguish the differences between accounts, to a conceptual evaluating level, where students attribute the differences to perspectives of the authors and believe that no true account can be established.

3.2.3 Multi-dimensional theories. Schommer (1990) investigated the development of secondary students' beliefs regarding the nature of knowledge and learning strategies, their epistemological beliefs and the effect of these beliefs on their academic performance. Her multi-dimensional theory of epistemology resulted in a considerable shift in the epistemological research field. Schommer presented a set of independent dimensions in her epistemological theory. Schommer's first dimension was built on the foundation of the works done by developmental theorists (Baxter Magolda, 2004; King & Kitchener, 2004; Perry, 1999) who believed in a transition from an absolutist to a relativistic understanding of knowledge. This dimension, ‘certainty of knowledge’, is related to the extent to which one considers knowledge as solid or uncertain and evolving. Developmental researchers consider this dimension as a continuum that moves from the views of absolute truth with certainty to a higher level in which knowledge is uncertain and evolving. King and Kitchener (2004) believed that at the reflective stages, students are open to new interpretations. Kuhn and Weinstock (2002) also discussed that at the highest stage individuals consider the possibility of having their theories modified by genuine interchange. Borda (2006) believed that many introductory science courses at the undergraduate level are “content-driven” and lead instructors to present science as a body of fixed facts. Such instruction makes students look at science from the outside and consider science as objective and static. This makes them believe that knowledge has the role of uncovering truths. Therefore, she warned instructors to be careful with the ways they use written accounts of science and teach writing in the science classrooms. Instructors should encourage students to avoid writing in a manner that represents science as a body of settled facts. Encouraging students to write in the first person helps them move from the level of considering science as a collection of solid facts to a level of constructivist views in which science is an “explanation-building endeavor” (Borda, 2006). Therefore, the factors related to this dimension are of great interest to me in this project.

The second dimension presented by Schommer (1990) is ‘the structure of knowledge’ in which knowledge is viewed on a continuum ranging from a body of isolated facts to an understanding of knowledge as highly interrelated concepts. Similarly, the other researchers believe that the lower level view of knowledge is seen as discrete, solid, knowable facts, while at higher levels individuals see knowledge as relative, interrelated concepts, and contextual (Hofer, 2000). These two dimensions (‘certainty of knowledge’ and ‘the structure of knowledge’) are related to the nature of knowledge. We have designed many questions in the introductory physics labatorials to help students think about the concepts discussed previously and relate them to the new concepts taught. In the reflective writing activity, relating recently introduced key concepts to previously studied concepts is one of the main marking criteria. Therefore, I was eager to study this dimension in my research project.

The ‘source of knowledge’ dimension is related to a range of views about the role of an authority. At lower levels of most of the models, knowledge originates outside and resides in an external authority (Hofer, 2000; Schommer, 1990). At this level knowledge is poured in the mind of students without their participation. This is one of the reasons why Eger (1992, 1993) emphasized using hermeneutics in science education. He explained that most students believe that knowledge is positioned in external authority and considering real world experiences and making sense of what they read avoids students looking upon science from the outside. When we ask students to provide examples related to real life, their real world experiences become a part of knowledge presented to them and this prevents them from considering science as an external entity. At the highest levels presented by Schommer, students construct their own understanding of what is presented to them and act as active participants rather than being passive receivers. In reflective writing, we ask students to write their own understanding of concepts to avoid them being passive receivers of physics concepts. A hermeneutical approach to science helps students become a part of learning science rather than being an outside observer (Eger, 1992, 1993). Gadamer (2013) expressed the importance of a way of being (which Borda (2006) refers to as a hermeneutic consciousness) over a way of understanding. Perry (1999) described this shift in students’ epistemology as a change from being a holder of meaning to a maker of meaning and being a part of the learning procedure. Similarly, King and Kitchener (2004) described a shift from passive viewers to active meaning makers. Since in reflective writing we ask students to explain their own understanding of concepts and make sense of the concepts presented in the textbook, it was of great interest to explore this dimension in my project.

The last two dimensions, ‘fixed ability’ and ‘quick learning’, are about students’ ways of learning. The control of knowledge acquisition dimension presented by Schommer (1990) is related to implicit-theories of intelligence (Dweck & Leggett, 1988; Dweck, 2000). Schommer (1990) named this dimension “innate ability” and explained that this dimension is related to what students think of intelligence. The fixed views of the innate ability dimension consider intelligence as an ability that you are born with and you cannot gain more. However, a more sophisticated view considers intelligence as a skill that can be developed (Schommer, 1990).

Schommer (1990) presented the ‘speed of knowledge acquisition’ dimension based on the study (Schoenfeld, 1989) completed about students’ beliefs in mathematics and the effects of their epistemologies on learning processes. This dimension ranges from the view that learning either happens quickly or doesn’t happen at all to the more sophisticated view that considers learning as a gradual process which needs time, continuous effort and persistence (Schommer, 1990). Prior epistemological studies were based on qualitative interview methodologies, but Schommer (1990) followed a quantitative factor analysis to analyze these dimensions.

Barbara Hofer (2000) believed that various epistemological models are made up of somewhat distinct, but perhaps interrelated, dimensions: the nature of knowledge (what one believes knowledge is) and the nature or process of knowing (how one comes to know) (Hofer, 2000). Hofer and Pintrich (1997) first presented a nested theory of epistemological beliefs with both ‘certainty and simplicity of knowledge’ contained within a broader area called nature of knowledge. The second broad area of nature of knowing encompasses two dimensions, ‘source of knowledge’ and ‘justification for knowing.’

Definitions of the first three dimensions presented by Hofer (2000) are consistent with Schommer’s theory. The fourth dimension in Hofer’s (2000) theory, ‘justification for knowing,’ reflects “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) evaluated these dimensions quantitatively and developed a disciplined-focused epistemological questionnaire. The items in Hofer’s questionnaire are similar to the questions that Schommer used in her epistemological questionnaire. A team of researchers familiar with the literature assessed the items and a group of psychologists worked on wording, content validity, and the relevance of the items to each of the four dimensions (Hofer, 2000). Students enrolled in psychology and science majors were asked to respond to the questions on a 5-point scale (1 = strongly disagree; 5 = strongly agree). Four factors were labeled; Certain/Simple Knowledge, Justification for Knowing: Personal, Source of Knowledge: Authority, and Attainability of Truth (more information about the survey questions is provided in Chapter 4).The survey questions are about a specific discipline in which students are enrolled. We used Hofer’s survey questions related to physics in this project.

Hofer concluded that in this factoring of the discipline-based instrument “certainty of knowledge” and “simplicity of knowledge” emerged and formed a single factor and “attainability of truth” that shows the extent to which an absolute truth is believed to be attainable by experts emerged unexpectedly as a single factor. ‘Justification for knowing: personal’ that incorporates the idea that knowing is justified by ‘individual opinion’ or ‘firsthand experience,’ also emerged as a single factor. There is no question about reasoning processes in solving problems in the

Hoffer’s questionnaire (Hofer, 2000). Cognitive models study students’ reasoning processes when they encounter a problem. As explained in Section 3.2.2, King and Kitchener (2004) used ill-structured problems and designed interviews to study how the epistemological beliefs of students are related to the way they make judgments about controversial issues.

3.2.4 Epistemological resource theory. Elby and Hammer (2010) believed that students have different epistemological beliefs in different contexts. We discussed Schommer’s dimension of “source of knowledge” which explains a continuum from knowledge receiver to an active constructor of meaning. Elby and Hammer (2010) believed that a student can be a knowledge receiver and at the same time an active constructor of meaning based on the context. Therefore, a student can hold both ideas simultaneously and employ one or the other depending on context and as a result the student’s epistemological framework cannot be evaluated simply with some questions about the role of authority in gaining knowledge. To explain the different epistemological beliefs that one student can have simultaneously, Elby and Hammer (2010) provided an example in their study (Epistemological resources and framing: A cognitive framework for helping teachers interpret and respond to their students’ epistemologies):

> “Many students expect that an ice cube wrapped in cloth melts more quickly than one left out in the air. One interpretation of the students’ thinking would be to attribute a misconception that some materials, such as blankets, jackets, and gloves, are inherently warm. But ask those same students to think about removing a hot pan from the oven, and they would view that same cloth as something that can protect their hands by “blocking” the heat. The resources framework invites an explanation of these different patterns of reasoning in terms of the context-dependent activation of cognitive resources.” (p. 3).

Elby and Hammer also explained that students taking various courses per semester, their epistemological beliefs may vary from one course to another. Such students have sophisticated personal epistemologies and can play different roles in different frames. In this project I want to focus on students' epistemological beliefs related to introductory physics courses. I keep in mind that due to the complexity of students' epistemological frameworks suggested by Elby and Hammer (2010), the students' answers could be different if they consider another topic in their minds while responding to the questionnaire items. Hofer's study also supported the notion that the programs in which students are enrolled influence their epistemological beliefs. She concluded that students enrolled in natural science programs see knowledge as more certain and unchanging than students enrolled in psychology programs. In psychology, students are more likely to consider personal knowledge and firsthand experience to gain understanding and justify knowing than in natural science. Natural science students are more likely to view authority and expertise as the source of knowledge than psychology students. More students in natural science than psychology believe that truth is achievable by experts (Hofer, 2000). This is partly due to different training received by students in the two different disciplines.

3.2.5 Domain specific models. The domain specific model is also known as discipline specific model (Hofer, 2000; Schommer and Walker, 1995). Schommer and Walker (1995) conducted a study to explore whether epistemological beliefs are similar across the domains. They asked participants to keep a particular discipline in mind while responding to the questions. They compared mathematics focused responses with the social science responses and concluded that the results gained don't support any considerable differences between domains. Schommer-Aikins et al. (2003) repeated this study and concluded that college undergraduate students' epistemological beliefs are reasonably "domain general." Jehng et al. (1993) studied the epistemological beliefs of students enrolled in different academic majors and concluded that students in social science are more likely to consider knowledge uncertain and willing to rely on their reasoning skills in learning. As explained previously, Hofer (2000) developed the Discipline-Focused Beliefs Questionnaire (DFBQ) and studied epistemological beliefs both for psychology students and for natural science students. Although the factor structure was similar for both student groups, the mean scores were considerably different. This analysis yielded the same four primary factors influencing the learning of the students in each group (certainty and simplicity of knowledge, justification for knowing, source of knowledge, and attainability of truth). However, the relative significance of each factor differed for the two groups. The results showed that natural science students saw knowledge in natural science as more certain and unchanging. Psychology students were more likely to consider firsthand experience to justify knowledge in psychology. Natural science students viewed authority as the source of knowledge more than psychology students. Natural science students also perceived that truth is attainable by experts more than psychology students.

3.2.6 Integrated models. There are distinctions among epistemological models and there is no unified conceptualization of personal epistemology. Some researchers have proposed integrated models that consist of dimensional, developmental, and contextual elements. Hofer (2000) believed that there are points of convergence among these various models. She explained that epistemological models "are made up of somewhat discrete, but perhaps interrelated, dimensions." (p. 380). She believed that it is time to think about how general and discipline-focused beliefs work together and benefit from the results of research done in cognitive psychology and cognitive development (Hofer, 2001). Hofer (2001) also emphasized the need to benefit from the models that consider the contextual nature of epistemological beliefs: "We may be moving toward an integration of ideas from multiple models: *an identifiable set of dimensions of beliefs, organized as theories, progressing in reasonably predictable directions, activated in context, operating as epistemic cognition"* (p. 377). I also believe that there are common points among various epistemological models and considered an integrated model to assess the epistemological beliefs of introductory physics students in MRU. I will explain these common points (epistemological dimensions) in this project.

Integrated models are seen in the works of multi-dimensional researchers who believe in developmental components within epistemological dimensions (Bendixen and Rule, 2004) and the works of developmental theorists who believe that developmental stages may vary by domain (Clinchy, 2002). In this project, the epistemological results provided in Chapter 9 may reflect what students think about the introductory physics course. I am aware that students may function at a different level in other subjects. The disciplined-focused epistemological beliefs questionnaire developed by Hofer (2000) is used in this project. Hofer used a discipline-focused epistemological beliefs questionnaire to assess and compare the epistemological beliefs of both natural science and social science students. Appendix B shows the items in each factor of this questionnaire. The results are discussed in Chapter 9.

Although the models discussed have different characteristics, there are points of convergence among these models about what students believe knowledge is and the ways they gain knowledge (Hofer, 2000). Hofer (2000) categorized the common dimensions among all these models into two broad areas: the "nature of knowledge" (ideas about what knowledge is) and the "nature or process of knowing" (ideas about how to come to know). Under nature of knowledge, there are the "certainty of knowledge" and "simplicity of knowledge" dimensions, and the area of “nature of knowing” contains “source of knowledge” and “justification of knowledge” dimensions.

Students’ epistemological beliefs are an important area for research that may provide further insight into how students make meaning and how this in turn influences learning (Hofer, 2000). Epistemological beliefs have been shown to affect study strategies, and academic performance (Hofer, 2000; Schommer, 1990). It is important to understand the number and types of dimensions in order to understand the students’ epistemological beliefs and their relationship with students’ learning. Although there are many models and theories related to students’ epistemological beliefs and learning, there has been little work to test the dimensions suggested for science students. Hofer (2000, 2001) is one of the researchers who showed that epistemological beliefs vary based on the field of study and tested the dimensions of personal epistemology of science students. In this study, we used the discipline-focused epistemological beliefs questionnaire for physics to see whether a combination of reflective writing and labatorials change students’ epistemological beliefs. In the following section I explain each dimension of Hofer’s questionnaire. After discussing the dimensions and their importance in this project, I will provide an explanation of Hofer’s questionnaire and its factors.

3.3 The Dimensions of Personal Epistemology in Hofer’s Questionnaire

As discussed in the previous section, Hofer (2000) believed that there are two main dimensions that are common among the various epistemological models: the nature of knowledge (what one believes knowledge is) and the nature or process of knowing (how one comes to know). There are “certainty of knowledge” and “simplicity of knowledge” dimensions under the area of nature of knowledge. The area of nature of knowing contains “source of knowledge” and “justification of knowledge” dimensions. In this section we discuss the dimensions covered in Hofer’s questionnaire.

3.3.1 Certainty of knowledge. This dimension is related to the extent to which one considers knowledge as fixed and solid or more fluid and dynamic. The developmental psychologists consider this as a continuum that changes by time from a solid to a more fluid view (Hofer, 2000). At earlier stages, there is an absolute truth with certainty, while at more developed stages knowledge is considered uncertain and evolving. King and Kitchener (1994) believed that students are open to new interpretation at the highest stage of reflective judgment. Kuhn (1991) argued that at the highest stage individuals welcome possibilities and challenges to modify their ideas. Borda (2006) believed that the way introductory science courses are presented lead students to consider science as a body of fixed facts. A big motivation behind student-centered activities such as reflective writing is to provide an opportunity for students to question their pre-understanding and any new knowledge presented to them and to help them move from considering knowledge as fixed and solid to more fluid and dynamic. This is what Eger (1993) and Borda (2006) considered as a hermeneutical approach to science. Therefore, this dimension is of great interest to explore in this project.

3.3.2 Simplicity of knowledge. As discussed at the beginning of this chapter, Schommer (1990) believed that knowledge is viewed on a continuum as a body of facts or as highly interrelated concepts. We also reviewed the other models considering the lower level view of knowledge as discrete, concrete, knowable facts and higher level view of knowledge as relative, contingent, and contextual. We have designed many questions in the introductory physics labatorials to help students think about the concepts discussed previously and relate them to the new concepts taught (Appendix B). In a reflective writing activity, relating recently introduced key concepts to previously studied concepts is one of the main marking criteria (Appendix A). Therefore, this dimension is also of great interest to study in this research project.

3.3.3 Source of knowledge. At lower levels of most of the epistemological models, knowledge is created outside the individuals and exists in external authority (Hofer, 2000). This is one of the reasons why Eger (1991, 1992) emphasized the use of hermeneutics in science education. He argued that most students believe that knowledge is positioned in external authority and considering real world experiences and making sense of what they read avoids students looking upon science from the outside. Hermeneutics helps them be engaged in knowledge by constructing their own understanding and being a part of learning science not an outside observer. Gadamer expressed the importance of a way of being (which Borda (2006) refers to as a hermeneutic consciousness) over a way of understanding. Perry (1999) described this shift in students' epistemology as being a holder of meaning to a maker of meaning and being a part of learning procedure. Similarly, King and Kitchener (1994) described a shift in the process of learning at the highest stages from being an observer and receiver of knowledge to an active constructor of meaning. Since in reflective writing we ask students to explain their own understanding of concepts and make sense of the concepts presented in the textbook, it is of great interest to explore this dimension in my project.

3.3.4 Justification for Knowing. This dimension is related to evaluation of knowledge claims and the extent to which students use evidence or personal opinion to justify knowledge (Hofer, 2000). Since reflective writing is about interpretation and making sense of concepts, it is of great importance to find out how students evaluate knowledge claims and explore whether they use evidence or rely on authority and expertise. In the lower levels of the reflective judgment model (King & Kitchener, 1994), students justify knowledge through observation or authority. They may also justify knowledge based of what feels right. While, at higher levels students use reasoning and begin to personally evaluate knowledge and the views of authorities. It is interesting to me to explore this dimension since based on my experiences in the introductory physics labs, many students try to use the experimental results to prove what they see in the textbook or what they learned in the classroom. As King and Kitchener (1994) explained, I have also observed students who explain the experimental results based on what feels right. In addition I have faced students who tried to change the gained experimental results to be able to prove what they were taught in the course.

3.4 Discipline-focused Epistemological Beliefs Questionnaire

In the Sections 3.3.1 to 3.3.4, I discussed why each dimension of Hofer's epistemological questionnaire is of value to my work. The discipline-focused questionnaire contains items that Hofer and Pintrich (1997) adapted from existing instruments (Perry's Checklist of Educational Values and Schommer's epistemological beliefs questionnaire). They added more items to address the four discussed dimensions of epistemological models (Hofer & Pintrich, 1997). A team of researchers familiar with the literature developed the questionnaire and three psychologists reviewed the questionnaire to check wording, content validity, and the relevance of the questions to each dimension (Hofer, 2000). In this project, we used the Hofer's questionnaire for physics students. Students responded each of the 27 items on a 5-point scale (1 = strongly disagree; 5 = strongly agree). Hofer (2000) used Discipline-focused epistemological beliefs questionnaire to find the loadings of each item and identified four factors. These factors are: (1) certain/simple knowledge (eight items); (2) justification for knowing: personal (four items); (3) source of knowledge: authority (four items); and (4) attainability of truth (two items). In the analysis done by Hofer (2000) to find out the factors of the discipline-based instrument, certainty of knowledge and simplicity of knowledge emerged as one factor (Hofer, 2000). 'Justification for knowing: personal' stands for the view that personal opinion or firsthand experience justify knowledge and knowing. This factor does not involve questions related to evaluation of evidence or assessment of authority opinion (Hofer, 2000). 'Source of knowledge: authority' is about the extent to which students rely on expert knowledge, texts, and any external authority as the source of knowledge. An additional factor called 'attainability of truth' showed up in Hofer's analysis regarding the degree to which students believe that truth is attainable by experts (Hofer, 2000). The discipline-focused epistemological beliefs questionnaire for physics subject is presented in Appendix C.

As explained in Section 1.5.2.5, Kalman's group has qualitatively studied changes in students' epistemological beliefs by using reflective writing with collaborative group activities (Kalman, 2009). In this study we quantitatively explore the possible epistemological changes that may have caused by using reflective writing in combination with introductory physics labatorials. The quantitative analysis of Hofer's survey with a discussion of each factor for both experimental and control groups is presented in Chapter 9.

A research study on 'epistemology in science and the evolution of science philosophy' was done by Xiang (2006) in the department of physics at Concordia University. Xiang compared the evolution of science philosophy and epistemology and discussed the similarities with the evolution of hermeneutics. In Section 2.1.2 I discussed that Dilthey distinguished between the natural and social sciences. He believed that natural science methodologies explore cause and effect from the particular to the general, while the relationship between the parts and the whole is of great interest in social science. Gadamer was critical of Dilthey for distinguishing between natural science and social science. For Gadamer, meaning in both natural and social science is always an experience, an event or a moment of application (Packer, 2010). There is a range of disagreements about the definition of science. My opinion about science is close to Gadamer who believed that meaning in all fields (natural science and social science) is about being actively engaged in making sense of an experience or an event. The field of science education has been influenced by understanding, and performing, the characteristics and practices of professional scientists (Russ, 2014). Although there is no single definition of the ‘science’ and ‘epistemology of science,’ many science educators believe that understanding professional practice of the scholars in natural and developing a conception of how knowledge is constructed within science is related to the ‘epistemology of science’ field (Lederman, 2007; Russ, 2014). We should keep in mind that not all scholars in science studies or science educators agree on what constitutes the “epistemology of science,” or how to perform that epistemology in teaching and learning of science. Within science education there is a range of disagreements about what exactly scientists do, think, and say, what is most important for learners to do, think, and say, and what the nature and form of learners’ knowledge and practice of scientific epistemology should ultimately be (Packer, 2010; Russ, 2014).

I discussed various models of epistemology in Section 3.2. In each model, there are some researchers who believed that it is required to present a priori definition of science before studying students’ epistemological beliefs. Some researchers in these models believed that a priori definition of science can create a “potentially artificial discontinuity between the contexts of science and nonscience by requiring a priori definitions of those contexts and problems that constitute science—in which case an epistemology of science is appropriate and useful—and those contexts and problems that do not” (Russ, 2014; p.391). The problem is that what constitutes science is not clearly defined or cleanly demarcated (Gieryn, 1983). If we wish to persist with a model of epistemology and learning that requires learners to decide on the scientificness of the context or problem first, then we either have to limit ourselves to the very clearest cases of science (e.g., how rainbows are formed) or we have to, in addition to teaching epistemology of science, also teach students how to identify science contexts. Ladyman (2002) believed that by using some definitions of 'science', there are some topics in the disciplines such as chemistry, biology, or physics that are not scientific. I believe that there is no certain border between natural science and social science and similar to Gadamer I do not agree with people like Dilthey who distinguished between natural science and social science and tried to present a definition of 'science' and 'science epistemology.'

Chapter 4: Methodology and Research Design

As discussed in Chapter 1(Section 1.5.2.5), reflective writing has been shown to be successful in helping students (Huang & Kalman, 2012; Kalman, 2011; Kalman & Rohar, 2010; Kalman et al., 2008). The primary research question in this study is to find out how reflective writing is a helpful activity. Certain questions cannot be easily addressed by quantitative methods such as “How are reflective writing and labatorials helpful?” or “How do students actually go about doing reflective writing?” or “Do they bring their pre-understanding into studying the course?” Answers to such questions are helpful for both educators, in terms of guiding future students, as well as researchers, who seek a deeper understanding of the processes involved in implementing such activities. Regarding the nature of such research questions we followed a qualitative research approach, as recommended by Corbin & Strauss (2008) and Packer (2010) in order to explore these issues in this research project. A qualitative research approach provides an investigation of an activity, a process or individuals in detail (Creswell, 2002; Packer, 2010). In this study we have conducted interviews to discover how reflective writing and labatorials are helpful and combined the qualitative analysis of the interviews with the analysis of writing products and epistemological surveys to answer our research questions. Corbin and Strauss (2008) believed that “qualitative research allows researchers to get at the inner experience of participants” (p. 12). Qualitative studies allow a great deal of detail to be collected that would not normally be easily obtained by other research designs. Patton (1982) believed that in qualitative studies, interviewing is a major source of data needed for understanding the phenomenon under study. Interviewing like any other data collection techniques has its strengths and its limitations. The interview is the best way (and perhaps the only way) to find out “what is in and on someone else’s mind” (Patton 1982).

The analysis of the quantitative epistemological data addresses whether the combination of reflective writing and labatorials have an impact on students' personal epistemologies, whereas the qualitative data analysis focuses on the interviewees' perspectives on reflective writing and labatorials to investigate how these activities are helpful. In this mixed methodology, the quantitative analysis of the epistemological survey provides additional sources of information not provided by the qualitative data. Therefore, quantitative data play a supportive role to provide more information about using reflective writing in combination with labatorials.

In this study, we have addressed two main research questions. The primary question is:

1. How is reflective writing helpful at achieving effective students learning outcomes?

In introductory physics courses in MRU, students provide their reflective writing assignments before doing labatorials. Therefore, the secondary research question is:

2. How are 'labatorials' helpful in introductory physics courses in MRU?

We collected and analyzed two kinds of qualitative data: students' reflective writing products and interview transcripts (see Appendix D for interview questions) to address our primary research question. The last part of the interview focused on labatorials to address the secondary research question. We also analyzed the anonymous comments about labatorials left by students to validate the interviewees' statements about labatorials. Semi-structured interviews were completed at the beginning and end of the 13-week course. 7 students were interviewed in fall and winter 2014. We compared the pre- and post-interviews to see if students constructed reoccurring categories that might reveal underlying themes regarding their views towards reflective writing and labatorials. We also looked at their writing products to see whether what interviewees said was consistent with what they actually did during the semester. We also assessed the writing products of 41 students who were not interviewed to triangulate with and. also looke for potential themes not included in the interviews. These 41 students gave the author (MS) permission to evaluate their reflective writing products. Detailed information about the interview questions, cases and students involved in this study will be presented in this chapter. Figure 4.1 shows the weekly lab schedule of Phys1201 course. As can be seen in Figure 4.1, students complete 10 labatorials during the semester and provide 9 reflective writing assignments about labatroails 2-9. Labatorials usually start in the second week of each semester. Students are asked to complete an epistemological survey on the first day of lab and complete the same survey at the end of the semester. Students are asked to write down their opinions about Phys1201 labs after completing labatorial 4, and labatorial 10. Labatorial 1 is like a workshop that provides an introduction to reflective writing activity and focuses on error analysis and instruction on reflective writing.

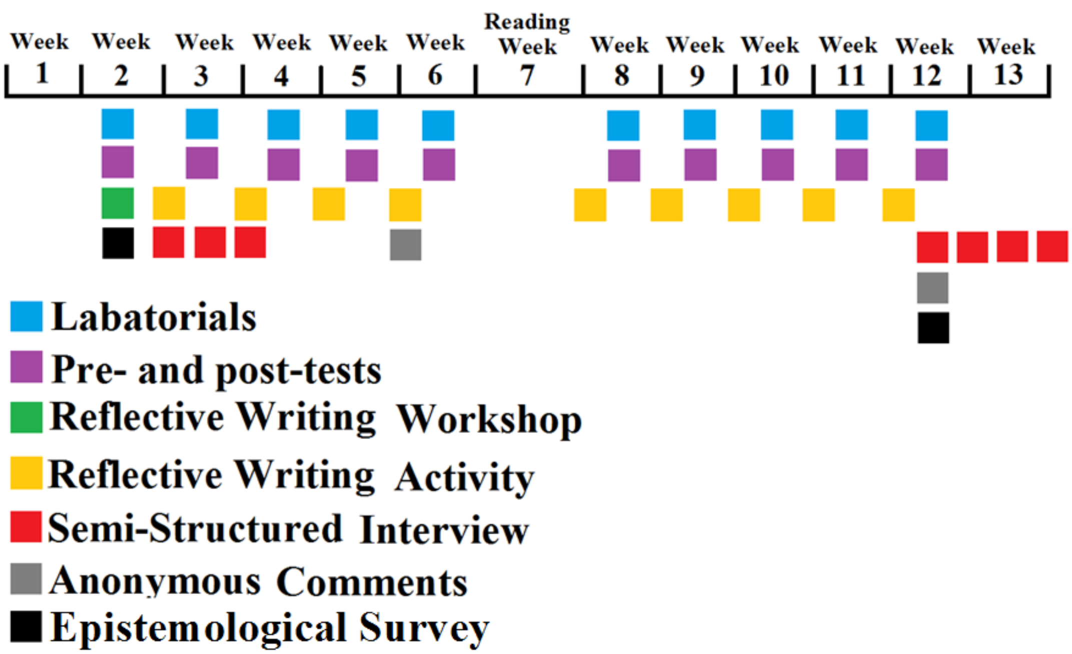


Figure 4.1: Weekly lab schedule of Phys1201 course

Table 4.1 presents the samples and the types of data collected to address the primary and secondary research questions.

<table>
<tr><th>Main Research Questions</th><th>Data</th><th colspan="2">Samples</th></tr>
<tr><td rowspan="5">Primary Research Question:
How is ‘reflective writing’ helpful at achieving effective students learning outcomes?</td><td rowspan="2">Qualitative Data</td><td colspan="2">7 students were interviewed</td></tr>
<tr><td colspan="2">48 writing products were assessed</td></tr>
<tr><td rowspan="3">Quantitative Data</td><td colspan="2">212 students completed the DFEBQ survey</td></tr>
<tr><td>Experimental Group</td><td>Control Group</td></tr>
<tr><td>110</td><td>102</td></tr>
<tr><td>Secondary Research Question:
How are ‘labatorials’ helpful in introductory physics courses in MRU?</td><td>Qualitative Data</td><td colspan="2">7 students were interviewed</td></tr>
</table>

Table 4.1: The samples and the types of data collected to address the primary and secondary research questions

A pilot study was done in fall 2013 in MRU. Three first year students enrolled in Phys 1201 and three students enrolled in Phys 1202 were interviewed. The pilot study provided me with ideas, approaches, and clues I had not foreseen before conducting the pilot study. Such ideas lead me to change some hypotheses, dropping some, or developing new hypotheses. Based on the analysis of the data collected in the pilot study I designed the following sub-questions to gain more information about the primary and secondary research questions in this study. Table

4.2 presents what set of data is used to address the sub-questions in this study and also presents which main research question can be addressed by each sub-question.

Sub-question	**The Main Research Question Addressed**	**Data**	**Samples**
What are the ways in which reflective writing changes students' strategies of learning physics?	Primary research question	Qualitative Data	7 students were interviewed
		Quantitative Data	212 students completed the DFEBQ survey
In what ways did the students' writing products improve during the semester?	Primary research question	Qualitative Data	48 writing products were assessed
Did students have a hermeneutical approach while doing reflective writing?	Primary research question	Qualitative Data	7 students were interviewed
			48 writing products were assessed
Does the combination of reflective writing and introductory physics labatorials change students' epistemology?	Both Primary research question and secondary research question	Quantitative Data	212 students completed the DFEBQ survey
How do students prepare their reflective writing assignments?	Primary research question	Qualitative Data	7 students were interviewed

Table 4.2: The set of data used to address the sub-questions in this study and also the primary and/or secondary research questions that can be addressed by each sub-question

This section explains how each sub-question is related to the main research questions in this study:

- What are the ways in which reflective writing changes students' strategies of learning physics?

In the pilot study I found that some interviewees had never used the textbook to study physics in high school. However, reflective writing activity encouraged them to read the textbook and they found that there are many helpful information and examples in the textbook that clarify the meaning of the principles and concepts. This finding provided me with the idea that reflective writing might change students' learning strategies during the semester. In addition, Kalman (2009) conducted a case study to find out whether or not reflective writing is helpful. He concluded that reflective writing improved the learning strategies, but did not provide any detail explaining the reasons. To study the ideas raised in the pilot study and to extend Kalman's studies on reflective writing I tried to find out whether or not reflective writing changes students' learning skills. The answer to this question is embedded in the main research question that investigates how reflective writing is helpful.

- In what ways did the students' writing products improve during the semester?

In Section 1.5.2.3 we discussed that Kirkpatrick (1984) believed that students who get a good understanding of concepts, their writing products should be logical in its construction and clear in its meaning. An improvement in the clarity of the students' writing products and the style of writing can be an indicator of improvement in understanding of concepts. An improvement in the clarity of writing products can be a hypothetical reason why reflective writing is an effective learning activity. In addition, the style of writing can help us find out whether or not students had a hermeneutical approach while preparing the writing assignments. An assessment of the students' writing products can help us find out whether what they said in the interview was consistent with what they actually did during the semester.

- Did students have a hermeneutical approach while doing reflective writing?

Writing-to-learn in science is about developing students' conceptual understanding of the topics and this cannot be aimed by rephrasing the materials presented in the textbook (Arons, 1990; Borda, 2006; Connolly, 1989; Eger, 1992, 1993; Kalman, 2006). One of the purposes of using reflective writing in introductory physics labatorials is to encourage students to engage with the textbook and take an active part in their learning instead of being a passive receiver of knowledge. Eger (1992, 1993) believed that critical thinking is fostered when we add questioning and communication into reading of a text. Kalman (2011) argued that when students experience a back-and-forth movement, they are evaluating the outcomes of their thinking. The back-and-forth movement of interpretation is more than the replacement of a body of terms by other groups of words without thinking about their meaning. The back-and-forth movement involves comparison and thinking to make sense of the ideas and concepts in the textbook (Eger, 1993). To explore whether or not students have a hermeneutical approach while preparing their writing products can help me address the primary research question that investigates how reflective writing is helpful at achieving effective students learning outcomes.

- Does the combination of reflective writing and introductory physics labatorials change students' epistemology?

In Section 2.3 we discussed the relationship between hermeneutics and epistemology. Kalman's group found that using reflective writing activity as the only activity in the introductory physics courses had no effect on the students' epistemological beliefs during the semester (Huang & Kalman, 2012). They combined reflective writing with conceptual conflict collaborative groups followed by an argumentative essay and developed experimental and control groups to study students' epistemological beliefs at the beginning and end of the course. The results gained indicated that students who experienced the combination of reflective writing with conceptual conflict collaborative groups and argumentative essays became more expert-like after the one-semester intervention, beginning to see physics knowledge as interconnected and evolving. In this spirit I decided to investigate the effects of the combination of reflective writing and labatorials on students' epistemological beliefs. I collected quantitative data to answer this sub-question. The results of the quantitative analysis can shed light on both primary and secondary research questions that are aimed to study how reflective writing and labatorials are helpful learning activities and also can make connections between these two learning activities.

- How do students prepare their reflective writing assignments?

In the Department of Chemistry and Physics in MRU, the first physics lab provides an introduction to lanbatorials and reflective writing activity. Lab instructors explain the purpose of using reflective writing and discuss each marking criteria of the rubric (Appendix A). Students are provided with an instruction to do reflective writing and are also given a reflective writing sample. The last activity of the first lab asks students to provide a short reflective writing product about the importance of 'units' in physics. To improve the strategies of doing reflective writing, I asked the interviewees participated in the pilot study to explain their strategies of doing reflective writing. Any different methodology that students take to prepare reflective writing can provide us with new insight about this activity and also help us improve the writing instructions in the future. Based on the pilot study, I also found that the strategies mentioned by the interviewees can provide information about whether students have a hermeneutical approach while doing reflective writing or they just provide a summary of the materials presented in the textbook.

4.1 Interview Questions and Analysis

The interview questions are on four main topics: students' perspectives on pre-understanding, their general way of learning in this course, the main aspects that make reflective writing a successful activity, and students' perspectives on labatorials. Table 4.3 presents which topics address the primary and secondary research questions and also shows what sub-questions are covered in each topic of the interview. I explain each topic and the rationale behind the questions asked in this section. The analysis techniques used to analyze the interviews are presented in Section 4.1.5.

4.1.1 Interview questions about pre-understanding. Gadamer (2013) believed that understanding and interpretation always occur from within a particular horizon. Within this framework, a student's horizon contains everything that s/he believes from the particular vantage point of encountering the dilemma on one hand and the student's understandings on the other. One's horizon is neither static nor unchanging (Packer, 2010). It has been argued that for novice students to acquire a full understanding of scientific concepts, they need to compare the presented knowledge with what they already know to be able to construct their comprehension of scientific concepts (Eger, 1992). Heidegger and Gadamer argued that without any idea beforehand of the presented knowledge, no progress can be made in interpretation and thus the pre-understanding takes on a positive role in hermeneutics (Eger, 1992; Gadamer 2013). While our preconceptions influence our views of the knowledge presented to us, the presented knowledge also informs and shapes our views of our preconceptions. If we are able to identify, question, and therefore broaden our preconceptions, we broaden our possibilities to construct our own understanding (Eger, 1992). From a hermeneutical perspective, students’ pre-understanding and how they use it can result in moving their horizon to have a larger overlap with the horizon projected by the textbook. Therefore, it is of great interest to find out what activities help them expand their horizon during the semester.

<table>
<tr><th>Interview Topics</th><th>The Main Research Question Addressed</th><th>The sub-questions Addressed</th></tr>
<tr><td rowspan="2">Pre-understanding</td><td>Primary research question</td><td>Do students have a hermeneutical approach while doing reflective writing?</td></tr>
<tr><td>Secondary research question</td><td></td></tr>
<tr><td rowspan="5">General way of learning Phys1201 course</td><td rowspan="4">Primary research question</td><td>What are the ways in which reflective writing changes students’ strategies of learning physics?</td></tr>
<tr><td>What are the ways that students’ writing products improved during the semester?</td></tr>
<tr><td>How do students prepare their reflective writing assignments?</td></tr>
<tr><td rowspan="2">Does the combination of reflective writing and introductory physics labatorials change students’ epistemology?</td></tr>
<tr><td>Secondary Research question</td></tr>
<tr><td>Students’ perspectives on reflective writing</td><td>Primary research question</td><td></td></tr>
<tr><td>Students’ perspectives on labatorials</td><td>Secondary research question</td><td></td></tr>
</table>

Table 4.3: The primary and/or secondary research questions as well as the sub-questions covered in each topic of the interview

During the pre-interview we explained the term "pre-understanding" to interviewees: "You may already have some ideas about physical concepts, such as force, velocity, mass and so on. These ideas may come from your former educational experience, or from your experience of the real world. Let's call all those ideas in your mind before you entered this course your pre-understanding." After defining the term "pre-understanding" we asked the question "Do you bring your pre-understanding into studying for this course?" to find out whether students identify and use their preconceptions in studying for the Phys1201 course. If their answer was positive we asked them to explain the activities that helped them use their pre-understanding.

Most first year students coming from high school view physics as loosely connected pieces of information to be separately learned, in contrast to a coherent web of meaningful interconnections to be tied together (Hammer, 1994; McCaskey, 2009; Sandoval 2005). One of the main purposes of using reflective writing in labatorials was to help students think about the connections among various physics concepts. This was also one of the main marking criteria of the reflective writing activity (Appendix A). In this regard it should be noted that Eger (1993) believed a hermeneutic approach in education helps to oppose "decontextualization". Eger believed that a hermeneutical approach in science contextualizes the problems and provides an opportunity to see the connections among various phenomena and as a result makes the problems more understandable. He also believed that abstract ideas are more understandable when they are seen in real life situations. We explored what interviewees thought about the "relationship between force and motion" at the beginning of the semester. During the post-interview we again asked what they had thought about the "relationship between force and motion" at the beginning of the semester and also asked about their present ideas about the relationship between these two concepts. We then asked them to explain the activities that helped them move from their ideas about the relationship between motion and force at the beginning of the semester to their present ideas at the end of the semester. We also used the “relationship between force and motion” as an example of pre-conceptions formed prior to learning in the class due to experiences in the real world. Eger (1992) explained that some notions about natural phenomena, that develop prior to formal schooling, which disagree with science, persist after the relevant subjects have been taught. He stated that such ideas do not always prevent students from achieving success in the course (Eger, 1992). Eger (1992) argued that these pre-conceptions are due to experiences in the real world and so they are formed prior to any scientific reflection. Eger (1992) argued that “What actually happens then is not ‘correction’ by science of a mistaken idea, but an extension of language reflecting an extension of concept.” (p. 343). For instance many students believe that when a ball is thrown upward, the acceleration is zero at the top point of its motion. This is an example of the ideas that many students have before taking the course and it may persist after the related topic is taught. They do not see the conflict between their pre-understanding and the textbook, and they assimilate new knowledge into their own system. But if a student is an effective learner then the student will see the conflict and go back and forth between the two using some form of scientific thinking and reasoning and in the process accommodate the new knowledge with a revision of their pre-understanding. The first part of the interview also focused on the activities that encouraged students integrate their pre-understanding with the new materials presented to them. The activities mentioned by students were explored deeply during the interview.

4.1.2 Interview questions about general way of learning this course. We asked students to explain how they studied for the Phys1201 course. Based on interviewees’ responses to this main question, we asked specific probe questions to find out what strategies they took to learn physics during the semester and how reflective writing and labatorials influenced their learning strategies during the semester. Interviewees also talked about their expectations of the Phys1201 course and labatorials and the strategies they took to meet their expectations by the end of semester.

4.1.3 Interview questions about students' perspectives on reflective writing. We designed specific questions to find out what students think of the reflective writing activity and what characteristics of this activity make it helpful. Students' perspectives on pre-understanding and the strategies they took to learn this course also helped us find how reflective is helpful.

4.1.4 Interview questions about students' perspectives on labatorials. Students' perspectives on labatorials were explored in detail. They explained how they worked on labatorial worksheets and discussed whether they gained what they expected out of labs. Since we conducted semi-structured interviews, interviewees' general ideas about labatorials were followed by specific probe questions to provide detailed information about how labatorials are helpful.

4.1.5 Interview analysis

Packer (2010) believed that it's the research question that drives the design of research and thus the investigators should design a study to answer the research questions, not fit the questions into a convenient design. The exploratory nature of the research questions in this study encouraged me to conduct a qualitative research investigation to explore how reflective writing and labatorials are helpful. "A standard practice for qualitative research has become accepted in which interviews are conducted, the data are coded, and the results reposted in the form of summaries written in formal language" (Packer, 2010, p. 42). Semi-structured interviews provide a great deal of latitude in the way interviewees answer and even the topics that they discuss. The aim of semi-structured interviews is to encourage the interviewees to speak in their own words to investigate a phenomenon in depth (Corbin & Strauss, 2008; Packer, 2010). Data collection and analysis is a simultaneous activity in qualitative research. Analysis begins with the first interview in this research work. Emerging insights and feelings direct the next phase of data collection, which in turn leads to modification or reformulation of one's questions, and so on. Once a decision has been made to end simultaneous data collection and analysis, the information must be organized so that intensive analysis can begin (Patton 1982; Yin 1986). Yin (2009) called this organized material the "case study data base" and Patton (1982) called it the "case record." Developing the case record involves some fairly simple sorting of all the data. The data need to be organized according to some scheme that makes sense. In this study I organized the interviews according to the dates they were conducted to create a case record. After creating a case record, all the data that have been gathered together and organized sequentially (the case data base or the case record) were read through several times from beginning to end. While reading, I wrote down notes, comments, observations, and queries. I established a dialogue with the data, asking questions of it, and making comments to code the data. Ryan and Bernard believed that "coding is the heart and soul of whole-text analysis" (Ryan & Bernard, 2000, p.780). Ryan and Bernard explained that coding involves "finding themes," and "themes are abstract (and often fuzzy) constructs that investigators identify before, during, and after data-collection" (Ryan & Bernard, 2000, p.780). The objective of the coding process is to make sense out of the case data base, divide it into text or image segments, label the segments with codes, examine codes for overlap and redundancy, and collapse these codes into broad themes (Creswell 2007). Creswell believed that although there are no set guidelines for coding data, a general trend of coding involves segmenting and labeling text to form descriptions and broad themes in the data. In this study, I followed the coding strategies presented by grounded theory approach. Coding in grounded theory involves the twin practices of abstraction and generalization. Abstraction practice involves separating a whole into elements that are distinct from one another. These distinct elements shape their original context. Generalizing practice involves finding what is common or repeated among these elements (Corbin & Strauss, 2008; Packer, 2010). I broke each student's interview into small segments and compared each segment with the whole interview transcript. I also compared each segment with the other students' interview transcripts. After coding the entire text, I made a list of all code words and then grouped similar codes and found the redundant codes to reduce a list of codes to a smaller, more manageable number. It is important to reduce the list of codes to get five to seven themes or categories. Themes are similar codes aggregated together to form a major idea in the data base (Creswell, 2007). I provide an example of the statements mentioned by some interviewees to explain how analysis was done in this research work:

> Student A: "*I read the textbook to do reflective writing assignment and after that I solved the textbook problems and the ones on mastering physics. I found that I could solve the problems better when I read the textbook… When I started reading the textbook to do reflective writing, I found many details and explanations that were not covered in the class and lecture notes and made me understand the material better. In my opinion I understand something when I can teach it or explain it. Reflective writing is like explaining materials. By understanding the concepts better of course you can solve the problems better*."

> Student B: "*At the beginning of the semester I tried to solve the problems and working on the assignments without knowing the concepts behind so I got terrible marks*

in assignments. Then I changed the way I studies physics and tried to understand all concepts well before getting involved in solving problems. When labatorials started then I had to provide a writing assignment for each lab and this made me read each section of the textbook so carefully. I felt like I realized many reasons behind what I just memorized in high school so dealing with problems became easier for me."

Student C: "*It [RW] made me read the book. It [RW] very much helped me to understand the concepts. Well, first you need to know the principles and then use the principles to solve the problems. Reflective writing improved my problem solving skills.*"

Student D: "*I try to understand the principles to be able to apply them to solve problems. Well, reflective writing made me read the textbook. There is never enough time in the class to cover everything. When I read the textbook to prepare my reflective writing I found lots of details that were not covered in the class and I was better at solving problems and answering conceptual questions*."

Students E: "*If you memorize physics you can't solve any problem. Memorizing the definitions and having a formula sheet don't work unless you know the meaning behind each equation and understand the concepts behind the formulas. Writing assignments helped me understand the meaning of the concepts. I thought about the concepts and used them to explain my own experiences. I planned to do my writing assignments [RW] on Fridays and assignment problems on Saturday. Writing assignments helped me understand the materials and read the book to be prepared to answer the assignment questions and solved the assigned problems*."

Student G: "*In physics we need to analyze the problems. It needs reasoning. For example we use one principle to solve a specific problem, but we should keep in mind* *that that principle applies to other problems too. Writing assignments helped me find the connection among various principles and improved my problem solving skills. We need reasoning to analyze the problems and use the same principles to answer numerous questions."*

As can be seen, different interviewees expressed the same ideas about the influence of reflective writing activity on their problem solving skills. These ideas are called repeating ideas, and they shed light on our research concerns. The search for repeating ideas accomplishes two points: it identifies units (parts) that can be taken to be common to all interview transcripts (whole), and at the same time it permits separating the interview transcript into units whose context can be ignored. The assumption is that what is common among all interview transcripts is general (Corbin & Strauss, 2008; Packer, 2010). Now the meaning of each unit needs to be defined and written and this meaning must be both abstract and general. In the example I am considering here, the meaning is "reflective writing improved interviewees' problem solving skills." This meaning is attributed to the interviewees: it is "the idea" that was "stated" by each interviewee. Coding is a matter of associating one or more categories with each incident of data. The researchers need to read through the materials several times to code each incident of data into as many categories of analysis as possible. It is needed to look at the concepts of the emerged categories to generate a "conceptual category." In this example, interviews with students who stated that reflective writing improved their problem solving skills, led to the abstraction of "influence of reflective writing on learning skills" conceptual category. MRU has purchased licenses for SPSS and NVivo software and there are training sessions for the researchers that are willing to use SPSS and NVivo software. I have used NVivo to explore the trustworthiness of the emerged codes and conceptual categories and also used SPSS to analyze the quantitative data in this research study. The trustworthiness strategies taken in this study are mentioned in Chapter 10.

In qualitative studies, interviewing is a major source of qualitative data needed for understanding the phenomenon under study. I am aware of the fact that interviewing, like any other data collection techniques, has its strengths and its limitations. The interview is the best way (and perhaps the only way) to find out “what is in and on someone else’s mind” (Patton 1982). Interviews allow a lot of detail to be collected that would not normally be easily obtained by other research designs. The data collected is normally richer and of greater depth than can be found through other experimental designs.

4.1.6 Survey analysis

The qualitative part of this project has priority and guides the project, while the quantitative part is nested in the qualitative section. The purpose of the quantitative part was to address a different question (does the combination of reflective writing and labatorials change students epistemological beliefs during the semester?) that can address the main research questions of the project (the primary and the secondary research questions) from a different level. In this study, we used the discipline-focused epistemological beliefs questionnaire for physics developed by Hofer (2000) to see whether a combination of reflective writing and labatorials can change students’ epistemological beliefs. To find out whether any possible epistemological change is a result of using reflective writing with labatorials, we designated two groups in fall 2014: an experimental group and a control group. The number of students in the experimental and control groups as well as the activities that they completed in fall 2014 and winter 2015 are presented in Tables 4.4 and 4.5 respectively. In fall 2014, eight Phys1201 lab sections were assigned to do reflective writing, while the remaining seven Phys1201 lab sections provided summary writing. There were 110 students in the experimental group who did reflective writing and 102 students in the control group who provided summary writing products during the fall 2014 semester. Many students, who take the Phys1201 course in the fall, then take the Phys1202 course in the winter. In winter 2015, there were 63 students enrolled in Phys1202 who had taken Phys1201 in fall 2014 and completed reflective writing assignments and took the epistemological survey. There were also 52 student enrolled in Phys1202 in winter 2015 who completed summary writing in fall 2014 and took the epistemological survey. To find out how students' epistemological beliefs change during two semesters, I gave these 115 students enrolled in Phys1202 course in winter 2015 an epistemological survey at the end of the semester. The next chapters focus on the analysis of both qualitative and quantitative data and the results gained.

	Number of observations in each group	**Activities**
Experimental Group	110	Reflective writing & labatorials
Control Group	102	Summary writing & labatorials

Table 4.4: The experimental design of the quantitative part of the project in fall 2014

	Number of observations in each group	**Activities**
Experimental Group	63	Reflective writing & labatorials
Control Group	52	Summary writing & labatorials

Table 4.5: The experimental design of the quantitative part of the project in winter 2015

In spring and summer 2014, I conducted a pilot study to get familiar with SPSS software and quantitative analysis of data. Dr. Ahmed Ibrahim from the University of California Riverside helped me in data analysis and evaluated the statistical methodologies that we used to analyse the quantitative data.

4.2 Course, Cases and Students Who Participated in this Study

Semi-structured interviews were completed during winter 2014 and fall 2014 at Mount Royal University. 7 students volunteered to participate in semi-structured interviews about their views on reflective writing and labatorials in Mount Royal University. Interviewees were given a $10 Tim Hortons gift card in appreciation of their time and participation. Regarding the research ethical issues, the author (MS) was not allowed to interview the students who were in her lab sections. Therefore, a graduate student of Concordia University (Wahidun N. Khanam) interviewed two students participated in the pilot study and Dr. Vahid Dehghanian read the consent form in the lab and interviewed the participants who were in the author's lab sections. The process of data analysis was done by the author (MS) and validated by the author's supervisors (Dr. Calvin S. Kalman & Dr. Robert Ian Thompson), and Kalman's research group members (Dr. Ahmed Ibrahim & Dr. Xihui Wang). Dr. Ibrahim ran statistical analysis to validate the quantitative analysis of the epistemological data and also assessed the interviews to validate the emerged codes. Dr. Kalman provided a rubric to analyze the interview transcripts. The analysis process of both qualitative and quantitative data was discussed in the weekly meetings held by Kalman's research group, the author and her supervisors. The interviews served several purposes. They helped us gather information on how the reflective writing activity and labatorials are viewed by a sample of the students. Most importantly, they also allowed us to see if the interpretations we made of the writing products were consistent with what interviewees told us. Finally, the interviews provided us with a basis for looking at certain individuals more closely regarding how students in Phys1201 provided their writing products and improved their learning skills during the semester.

Four first year students enrolled in the introductory physics I course (Phys 1201 course) participated in the interviews held in winter 2014. All interviewees had passed physics in high school (grade 12) and were enrolled in a General Science major. It is only at the start of the second academic year that students wishing to enter one of the other majors such as geosciences and biology will be asked to declare their intent to do so officially and thus all 1st-year students in these areas have general science as a major. Some students take up to two years of courses in Mount Royal University before transferring to another university of their choice to complete their program.

The first interviewee was a student who intended to study geosciences in MRU. We call her Student A. We refer to the second and third students, who planned to study chemistry, Students B and C respectively. The fourth student wished to enter the biology major beginning in his second year and we call him Student D. In fall 2014 we interviewed three more students enrolled in introductory physics I course (Phys 1201 course). We call them Students E, F, and G. All those interviewees also had passed physics in high school (grade 12) and enrolled in the General Science program. All students enrolled as General Science majors have to take Phys1201.

Phys1201 is a non-calculus course that provides an introduction to Newtonian mechanics. The topics covered include: vectors, motion in one and two dimensions including projectile motion, circular motion, forces, work and energy, impulse and momentum, and collisions. The textbook used in Phys1201 is called “Classical Physics”, which is a custom edition for MRU. It is taken from “College Physics: A Strategic Approach” (Knight et al., 2009), “Physics for

Scientists and Engineers: A Strategic Approach" (Knight & Knight, 2007). As mentioned in Section 4.1, we conducted a pilot study in fall 2013 and interviewed three first year students enrolled in Phys1201 course. All those interviewees had also passed physics in high school (grade 12) and enrolled in the General Science program. The pilot study helped assess the feasibility of the project in terms of sampling and analysis. It also helped us modify our research and interview questions and determine what resources and data we needed to improve this study. The data from the pilot project was not used in the final study.

Phys1201 is a 13-week course at Mount Royal University that includes 3 lecture hours per week, with weekly 1-hour tutorials and weekly 2-hour labatorials. There are 3 to 4 lecture sections and around 15 lab sections each semester. There were 16 students enrolled in each lab section. Course materials and homework are available online using Mastering Physics. All instructors make extensive use of "clickers" during the lecture. The grade is based on 15% labatorial, 5 % tutorials, 5% Mastering Physics, 20 % midterms, 50% final, and 5% in-class "clicker" questions. There are 10 labatorials during the semester. Labatorials usually start in the second week of each semester. The first labatorial focuses on error analysis and instruction on reflective writing. The reflective writing activity is worth 2 of the 10 for each labatorial mark. One week prior to each labatorial, lab instructors post a list of the textbook sections that are related to the concepts that will be discussed in the next labatorial. Students were asked to read the textbook sections and submit their writing materials to their lab instructor three days before each lab. Students provided 9 writing products during the semester. In fall 2014 we had four lecture sections taught by four physics instructors and 15 Phys1201 lab sections in Mount Royal University. There were 15 students in each lab section. One full-time lab instructor (the author

MS) taught eight Phys1201 lab sections and the remaining eight sections were taught by a part-time lab instructor. Table 4.6 shows the timeline of this study.

Task	Spring 2013	Summer 2013	Fall 2013	Winter 2014	Spring & Summer 2014	Fall 2014	Winter 2015	Spring & Summer 2015	Fall 2015
Course Work	Research Methodology in Education (EDER 603-20)		Advanced Research Methods (EDER 701-03)	Auditing Phenomenology & Hermeneutics (EDER 701-13)					
Literature Review	●	●							
Pilot Study			●		●				
Collecting Data			●	●	●	●	●		
Data Analysis			●	●	●	●	●		
Writing Thesis						●	●	●	
Submit Thesis									●

Table 4.6: Project timeline

In this study, we collected two kinds of qualitative data: students' reflective writing products and interview transcripts. The interview questions are on four topics: students' perspectives on pre-understanding, general way of learning this course, the ways in which reflective writing is helpful, and students' perspectives on labatorials. In the next chapter we focus on students' perspectives on pre-understanding. Chapter 6 and 7 discuss students' writing products and the key aspects that make reflective writing a successful activity. Chapter 8 presents students' perspectives on labatorials. In Chapter 9 we focus on students' learning strategies and the analysis of the epistemological survey data.

Chapter 5: Students' Perspectives on Pre-understanding

In this chapter I will analyze the interviewees' perspectives on pre-understanding and the activities that helped them use their pre-knowledge in phys1201 course. The pre-understanding analysis is based on both the pre- and post- interview statements, to give a complete picture of the students' initial state and evolution in their understanding and use of pre-understanding.

5.1 Student A's Perspectives on Pre-understanding

During the pre-interview, Student A explained his pre-understanding as what he had learnt in high school. He also stated that he tried to connect the physics concepts to his life experiences. Through the post-interview he mentioned that his pre-understanding at the beginning of the course contained what he learned in high school, but he rarely thought about them in life since he just memorized the concepts to pass physics in high school. In general he defined "pre-understanding" as a combination of experiences and knowledge gained. To clarify his statement, he provided an example: He learned how to float on water by himself and then he learned swimming from his father. He also learned some advanced techniques by watching a video on YouTube. He considered all these as his pre-understanding when he registered for a swimming training class. Student A felt the purpose of the course was to be able to solve physics problems. He thought that the reflective writing assignments reinforced concepts from the class and helped him understand the concepts better and as a result his problem solving skills improved during the semester. He clarified that he used to focus on memorization in high school, but he learned to use critical thinking and reasoning to study for this course. He felt the reflective writing activity helped him put the concepts into words and gain a better understanding of them. Student A was aware of changes in his horizon during the semester and explained that:

“[Some concepts in his horizon] *have changed completely such as Newton’s third law, the difference between velocity and speed. Some have been enriched. For example I knew about acceleration but I learned more about it in this course. I have also modified my understanding of collisions. I thought that when two objects don’t stick together then the collision between them is elastic but I learned about the conservation of kinetic energy in collisions.*”

It is interesting to see that reflective writing helped him compare the course materials with what he knew and what he had experienced before:

“*I compared what I read with what I knew and experienced before. For instance when I read about circular motion, I tried to compare the concepts with my experience on a roller coaster. I have experienced centrifugal force and so I compared my experience with this section of the textbook and inertia and it made perfect sense.*”

This is what Eger (1993) called the “expansion of preconceptions” and explained that this happens when a student compares the student’s own experiences and knowledge with new materials presented.

During the post-interview, Student A provided an example of the experiences when his pre-understanding didn’t match what he read in the textbook:

“*I thought that normal force and weight are action and reaction forces in Newton’s third law. It is written in the textbook that action and reaction have the same magnitude, but I had solved some problems that weight and normal force had different magnitudes. On the other hand the textbook says that action and reaction never cancel each other and so that confused me a lot. I decided to read those pages over and over and then found that action* *is from A to B and reaction from B to A and so I found that I have been thinking about two different forces acting on one object. It took a while but by drawing a free body diagram and reading the section of Newton's third law over and over, I could figure out what was going on.*"

This student believed that pre-understanding played a positive role in studying for this course:

"*I guess I learned Newton's third law better since I spent lots of time to solve the conflict between my pre-understanding and what I saw in the textbook. When you know about something and you read about it then you make comparisons and it makes you think deeply about it and you gain a better understanding I think.*"

I have assessed interviewees' writing products to see whether what they said in the interviews were consistent with what they actually did while preparing their writing products. Student A's writing products reveal that he actually made comparison between his pre-understanding and what he read in the writing assignments. For instance in the reflective writing assignment about Newton's second law he explained that:

"*Newton's second law means that if a body is accelerating, then there is a net force on it and we call this kind of motion an accelerated motion. This is consistent with the fact that net force is zero in a uniform motion. If the net force is aimed in a positive direction then it will create a positive change in velocity and therefore acceleration is positive. In the second assignment we talked about the sign of acceleration and when I compare this topic to the second assignment the concept of force and acceleration make perfect sense.*"

In Chapter 6, I will explain that making comparison between one's pre-understandings and what one reads in the textbook depends on the topic of the assignment.

In summary, based on the pre- and post-interviews with Student A, I concluded that this student considered pre-understanding as a combination of life experiences and the knowledge previously gained. He claimed that he used his pre-understanding in learning phys1201 course and his horizon expanded during the semester.

5.2 Student B's Perspectives on Pre-understanding

In the pre-interview, Student B defined his pre-understanding as a basic understanding of the main physics concepts that would develop during the semester. He appreciated the role of real world experiences in understanding the materials. In the post-interview he explained that his pre-understanding at the beginning of the semester was just a collection of words and terms in his memory:

> "*I used to memorize the concepts and formulas in high school. For instance I memorized the definition of weight without thinking about it. During the semester many concepts were familiar and so I tried to make sense of what I memorized. I asked myself this is what you remember but this is what this concept actually means and this helped me a lot.*"

He clarified that he referred to what he remembered from high school and tried to understand the reasons behind them. Thinking about real life situations also helped him gain a better understanding of concepts. Pre-understanding decreased his anxiety and helped him follow the class and as a result improved his understanding of the materials presented: "*when I see a new concept that I have no idea about I become nervous but when I have even a basic background about a subject then I am relaxed and I get a better understanding.*" He mentioned this fact as a reason why he liked reflective writing activities combined with labatorials.

In the post-interview, Student B mentioned that he was aware of changes in his horizon throughout the semester and believed that making sense of the materials and reasoning helped him expand his horizon: "*I tried to find out the reason behind each concept and so my understanding is not just a collection of words and terms. There are meanings behind each.*" Change in Student B's horizon was obvious when I looked at his writing assignments. His writing assignments improved in terms of clarity and style and he had more to say about the concepts by the end of the semester. For instance in his second writing activity he explained acceleration as: "*The textbook defines acceleration by the rate of change of velocity. I define acceleration as the change in velocity over the change in time.*" However, in his sixth writing assignment he explained Newton's third law:

> "*Everything comes in pairs right? Salt and pepper, left and right, up and down, north and south, fire and water. There are lots of other pairings in this world. Newton also observed this in forces. They come in pairs and are usually the opposite of each other. This is his third Law, for every reaction there is an equal but opposite reaction. They will exist in pairs or won't exist at all. My best friend is pushing on me to make me fall over, but I won't let him push me over. This is an example of Newton's third Law. He is applying a force on me to move, but I am applying an equal force but towards him.*"

In summary, based on the pre- and post-interviews with Student B, I concluded that this student's pre-understanding changed from a collection of words and terms to a combination of knowledge about the physics concepts and real life application of these concepts. He claimed that he used his pre-understanding in learning Phys1201 course and was aware of changes in his horizon.

5.3 Student C's Perspectives on Pre-understanding

When I asked Student C to explain her pre-understanding in the pre-interview, she specified that her pre-understanding contained what she learned in high school. She emphasized that she couldn't rely on life experiences since what we see in the textbook is related to ideal situations, while we live in a real non-ideal world:

> "*What I've learned in high school comes handy in this course for sure. To be honest I cannot rely on real life experiences to pass this course. What we see in the textbook is related to ideal situations, while we are living in a real non-ideal world.*"

She believed that there were some examples of physics principles in real life but she could not relate all physics principles to real life situations due to living in a non-ideal world. In the post-interview, when I asked about her pre-understanding at the beginning of the semester, she thought that it contained her world view. The way she viewed the world and all things that made her have such views were contained in her pre-understanding at the beginning of the semester. What she learned in high school and also her own world experiences shaped her views about the world. During the course she got familiar with the limitations and restrictions and by doing the reflective writing activity she tried to provide a real world example for each principle. Student C experienced a change in her pre-understanding during the semester. Some concepts in her pre-understanding changed and she learned more about some concepts in this course.

In the post-interview she provided an example to clarify changes in her horizon: "*when I rub my hand on a rough surface I can feel the heat but when I rub my hand on a smooth surface I feel less heat.*" She explained that by taking this course she had learned more about friction: "*I* *learned more about friction and what I learn can explain my experiences*”. Like Student B, Student C appreciated reflective writing as an activity that decreased her anxiety:

> “*I’m less worried when I see a familiar principle, because I know it already. Then I am prepared to learn more about it. when … all the principles presented are new then I get worried because I can’t learn lots of new things all together and then after learning two or three my mind stops working.*”

In summary, based on the pre- and post-interviews with Student C, I concluded that this student’s pre-understanding changed during the semester and she was aware of changes in her horizon by the end of the semester. In the pre-interview she claimed that her pre-understanding contained what she learned in high school, while in the post-interview she considered her life experiences as a part of her pre-understanding. She argued that she used her pre-understanding in learning Phys1201 course.

5.4 Student D’s Perspectives on Pre-understanding

In the pre-interview, Student D told me that his pre-understanding involved what he learned in high school. In the post-interview, he confirmed that his pre-understanding at the beginning of the semester was a basic knowledge in physics developed during high school. He thought the reflective writing assignments were good, and they helped him develop his knowledge further and think about the relationship between various concepts and the real world situations related to them. Student D believed that using real world experience in studying any physics course depends on the way you see the world around you. To clarify his point of view he provided an example:

> "*I drive to school every day and as you said I experience speed. But I don't look at that in terms of physics. If I see the world through the lens of physics then I have a scientific view of the world. It's like what happened to Newton. Many people experienced gravity but just one person had a scientific view of gravity.*"

Since reflective writing required students to provide examples related to real world situations Student D had to think about the phenomenon around and this made the course interesting to him: "*when you can explain your experiences by physics laws you get more interested in this subject" and "the real experiences made the concepts interesting and handy.*"

In the post-interview Student D appreciated reflective writing as an activity that helped him think about real world experiences and recall what he had learned in high school and compare them with what he saw in the book. At the beginning of the semester, it wasn't easy for this student to make a connection between physics concepts and real world experiences, but he found it interesting and helpful by the end of semester: "*When you think about your experiences you actually find the application of physics laws in the real world and this makes you enjoy the course. It's always enjoyable to know how the universe works.*" Reflective writing also helped him see the relationship among various concepts by the end of this course: "*When you learn physics more and more you will find more and more phenomena in the universe that can be explained by the laws of physics and you get surprised when you find unrelated phenomena that have similar explanations.*"

In summary, based on the pre- and post-interviews with Student D, I concluded that this student used his pre-understanding in learning phys1201 course. He claimed that his pre-understanding at the beginning of the semester was a basic knowledge in physics developed during high school, while his pre-understanding by the end of the semester contained the relationship between various concepts and the real world situations related to them. Student D was aware of changes in his horizon during the semester.

5.5 Student E's Perspectives on Pre-understanding

In the pre-interview, Student E explained that she had a basic knowledge of physics in high school. She attempted to recall what she learned in high school when she was sitting in the class listening to the instructor. She believed that her pre-understanding mostly contained what she had learned in high school, but what she saw around and experienced in life were also a part of her pre-understanding. Student E believed that her pre-understanding played a positive role in learning: "*When I already know something I understand it better. It is just like reviewing or recalling. I need to spend a great deal time learning the new concepts but it takes less to make sense of what you already know*." In the pre-interview Student E kept talking about the lecture instructor. Several times during the pre-interview she emphasized that when she faced a confusing concept she talked to the course instructor and she also provided several examples in which she gained a better understanding when the course instructor explained the concepts to her with more details. I believe Student E relied heavily on the course instructor at the beginning of the semester. She was aware of changes in her horizon at the beginning of the semester and explained that the conflicts between her pre-understanding and the presented materials and the help of instructor have helped shape her new ideas about classical physics:

> "*I learned speed and velocity in high school, but I thought that they were the same. I thought one is scalar and the other one is a vector and this is the only difference. When Syed [Student E's course instructor] taught these two concepts I got confused but I saw*

him during his office hours and he explained to me the difference between speed and velocity and then I got it."

Student E also mentioned reflective writing as an activity that changed her horizon and made her think about life experiences and the relationships among various physics concepts:

"*I reviewed my notes and then read the book to do reflective writing. I had to provide examples and it made me think about what I knew and what I had experienced. I compared my pre knowledge to the concepts in the book and tried to connect the concepts to my experience. I actually tried to explain my own experiences based on what I learned. For example, when I read about conservation of energy I tried to explain sweating in the gym based on this law. I actually couldn't make a link between various concepts in high school. Thinking about the various concepts in daily life and the way they are combined to explain a phenomenon helped me understand the connection between them.*"

Student E found the reflective writing rubric very helpful and tried to address all marking criteria while preparing her writing products.

In the post-interview she confirmed that her ideas about physics concepts changed during the semester. She believed that university physics was very different from high school physics. She explained that in high school if you memorize the definition of concepts and even the ways of solving problems you will end up with a reasonable final mark, but in college you need to learn the meaning of the concepts to be able to solve the problems and answer the conceptual questions. Her pre-understanding was a body of terms and definitions at the beginning of the semester that changed during the semester by learning new concepts and using reasoning and experiences to make sense of them:

“*I memorized physics laws and formulas in high school and it worked. But at the college level you need to understand physics. I learned that formulas are derived from the concepts. If you memorize physics you can’t solve any problem. Memorizing the definitions and having a formula sheet don’t work unless you know the meaning behind each equation and understand the concepts behind the formulas. Writing assignments helped me understand the meaning of the concepts. I thought about the concepts and used them to explain my own experiences.*”

In summary, based on the pre- and post-interviews with Students E, I concluded that this student used her pre-understanding in learning phys1201 course and emphasized that pre-understanding played a positive role in learning. She claimed that her pre-understanding at the beginning of the semester contained what she memorized in high school, but during the semester she thought about the meaning of the concepts and their applications in real life. She was aware of changes in her horizon during the semester.

5.6 Student F’s Perspectives on Pre-understanding

In the pre-interview, Student F explained that he didn’t learn physics in high school and he just had a vague memory that didn’t help him at all. He barely thought about life experiences related to physics concepts, but the real life examples provided by the course instructor helped him think about similar situations that he had experienced. He believed that he had a basic limited knowledge about several physics concepts that he had learned from scientific documentaries:

“*I honestly didn’t learn anything in high school. I just didn’t fail. I didn’t like physics in high school. I didn’t learn anything in high school. I just have a vague memory. Math and* *physics are not about memorizing. I memorized physics in high school and that is why I learned nothing. My pre understanding is so limited. It contains my own experiences and what I have learned from internet or media. For example once I watched a documentary about the oceans and I learned a lot about pressure.*"

Even if he explained that his pre-understanding was so limited at the beginning of the semester, he emphasized the positive role of pre-understanding in learning materials. He clarified his point of view on pre-understanding by explaining his pre-understanding in chemistry. Student F had a great chemistry teacher in high school and grasped a good understanding of introductory chemistry concepts. He believed that his great performance in university chemistry course is due to the knowledge that he gained in high school. In contrast, all physics concepts in Phys1201 course seemed new to him and in comparison with the students who had a good understanding of physics in high school, he had to spend more time to learn the concepts. He explained that most students found the first chapter so easy since it was a review of high school physics, but he had to spend a great deal of time to make sense of the materials in Chapter 1. I believe that the main source of knowledge for Student F was the course instructor. He emphasized that he learned the concepts better if someone knowledgeable explained them to him. For instance he was not able to think about real life examples related to physics concepts, but the examples provided by the instructor helped him think about similar life experiences. He also mentioned that he didn't take notes because he wanted to just focus on what the instructor said in the class and if the instructor wasn't available out of his office hours, he watched a YouTube video of a teacher explaining the concepts. Based on our discussion in the pre-interview, I believe that Student F highly relied on instructors to solve any conflict between his understanding and the materials taught in the course:

"*I learn better when someone explains something to me. That is why I don't take notes in* *the class. I just focus on what the professor says and I learn a lot. I actually go to the class and pay attention to what the professor says in the class. I didn't learn much in high school. I also don't think about my experiences, but when Alexis [Student F's course instructor] provides an example, I think about my similar experiences and it simplifies the materials. Alexis is a great teacher and simplifies everything.*"

He emphasized several times during the pre-interview that he learned nothing in high school and as a result he didn't rely on his own reasoning and judgment to make sense of the confusing concepts.

In the post-interview Student F explained that his pre-understanding changed and expanded during the semester. He explained that the textbook, assignments problems and what he had learned in the class, tutorial session, and labatorial sessions helped him expand his horizon and shape his present ideas. Student F emphasized that he did not enjoy writing assignments and he just found the reading part of reflective writing activity helpful. Reflective writing activity made him read the book and this expanded his pre-understanding, but for him the writing part wasted his time and had no role in understanding the physics concepts:

"*I am not a fan of writing. I learn when I listen not when I write. Writing assignments are definitely helpful but they were not very helpful to me. It was great to have an activity to make us read the book, understand the concepts and follow the class. It was also great to know the concepts before doing the experiments. But I am not a fan of writing. I enjoyed reading more.*"

Students F's writing assignments also show that he did not enjoy the writing part.

In summary, based on the pre- and post-interviews with Students F, I concluded that this student was the only interviewee who claimed that he did not use his pre-understanding in learning Phys1201 course. He argued that he didn't learn anything in high school, but his pre-understanding changed and expanded by the end of the semester.

5.7 Student G's Perspectives on Pre-understanding

In the pre-interview, Student G explained that her pre-understanding contained her life experiences and her high school knowledge in physics and mathematics. She explained that in all disciplines when you are taught new concepts, you think about what you already know about them and so Student G believed that pre-understanding plays an important role in learning materials:

> "*When teachers talk about various things, I think about what I knew already. This happens automatically and I have no control over it. If someone starts talking about the moon, what I already know comes to my mind and some questions may come to my mind.*"

Student G explained that when she had a conflict between her pre-understanding and the materials presented in Phys1201, she first attempted to solve the conflicts by herself and if she wasn't able to solve the inconsistency, she went to the instructor's office hours:

> "*I think about what I know and what I am taught. If there is any conflict then I try to solve it otherwise I move on. I try to address the conflict first and if it goes nowhere then I ask my teachers. I always go to office hours and ask questions.*"

Students G believed that thinking about the application of theories in real life makes the concepts easier to understand.

In the post-interview Student G emphasized that her pre-understanding expanded during the semester and lots of activities such as assignment problems, tutorials, labatorials, writing assignments, and classroom lectures and activities helped her shape her present ideas. She used her reasoning and tried to find the relationship among various physics concepts:

> "*In physics we need to analyze the problems. It needs reasoning. For example we use one principle to solve a specific problem, but we should keep in mind that that principle applies to other problems too. Writing assignments helped me find the connection among various principles and improved my problem solving skills. We need reasoning to analyze the problems and use the same principles to answer numerous questions.*"

Besides learning new concepts, her knowledge of some materials was enriched and in some cases her pre-knowledge was corrected. She became able to explain the science behind many phenomena and appreciated the extensive use of examples in Phys1201 classrooms and labs:

> "*The course professor and the lab instructor emphasized the application of theories in the class, labatorials and writing assignments. Thinking about the application of theories makes them easier to understand. For instance conservation of mechanical energy is confusing, but it makes perfect sense when you think about a swing.*"

In summary, based on the pre- and post-interviews with Students G, this student used her pre-understanding in learning Phys1201 course and emphasized that pre-understanding played a positive role in learning. She claimed that her pre-understanding at the beginning of the semester contained her life experiences and her high school knowledge in physics and mathematics. Her utilization of her pre-understanding was enriched during the semester and she was aware of changes in her horizon.

5.8 Activities that Engaged Students' Pre-understanding

Interviews allowed us to compare what students thought about pre-understanding at the beginning of the semester and how they defined their pre-understanding in the post-interview. They explained the activities that helped them use their pre-understanding and talked about the changes in their ideas during the semester. In both pre- and post-interview all interviewees except for Student F mentioned that they brought their pre-understanding into studying for this course. Students F mentioned that he did not learn physics in high school and according to him there was no pre-understanding. All interviewees experienced changes in their pre-understandings during the semester. They all believed that pre-understanding had a positive role in learning and explained the activities that helped them use their pre-understanding. Table 5.1 and 5.2 show the interviewees' explanations of using pre-understanding during the pre- and post-interviews.

As can be seen in Table 5.1, in the pre-interview, Students A, B, and C mentioned that they used their pre-understanding in two ways: making connection between what they knew before taking the course and what was presented in the class; and making connection between physics concepts and real world examples. During the post-interview they all mentioned one more way of using pre-understanding in this course: making connection between what they knew and what they saw in the textbook.

As can be seen in Table 5.2, in the pre-interview Student E explained that he used his pre-understanding in two ways: making comparisons between what he learned in high school and what was presented in the classroom; and making connections between some physics concepts and real life experiences. Student G mentioned one way of using pre-understanding in the pre-interview: making connection between what she knows and what the professor says in the class. As discussed before, in the pre-interview Student F explained that he didn't use his pre-understanding and he wasn't able to make connections between physics concepts and their applications in real life. During the post-interview Students E, F, and G mentioned that they all used their pre-understanding in solving physics problems and explained that they all made connections between what they knew and what they saw in the textbook.

As can be seen in Tables 5.1 and 5.2 all interviewees considered making connections between what they knew and what they saw in the textbook as a way of using pre-understanding by the end of the semester. It is interesting to see that the students' possibilities of using pre-understanding has expanded during the semester and they all specified the reflective writing activity as an experience that made them read the textbook and compare the materials in the textbook with their pre-understanding. When there are more activities that help us identify and use our pre-understanding, the possibility of questioning our pre-knowledge increases and this empowers a hermeneutical approach. As seen in Table 5.1 and 5.2, reflective writing provided an opportunity for students to compare what they knew before with what they find in the textbook.

Students participated in winter study	**Ways of using pre-understanding in learning new materials in the Phys1201 course.** **(pre-interview, at the beginning of the semester)**	**Ways of using pre-understanding in learning new materials in the Phys1201 course.** **(post-interview, at the end of the semester)**
Student A	Making connections between what he knows and what the professor says in the class. Making connections between physics concepts and his life experiences.	Making connections between what he knows and what the professor says Making connections between what he knows and what he sees in the textbook Making connections between physics concepts and his life experiences.
Student B	Making connections between what he knows and what is presented in the class. Making connections between physics concepts and applicable examples.	Making connections between what he knows and what the professor says Making connections between physics concepts and his life experiences. Making connections between what he knows and what he sees in the textbook
Student C	Making connections between what she learned in high school and what is presented in the class. Making connections between some physics concepts and real life situations.	Making connections between what she learned in high school and what is presented in the class Making connections between physics concepts and real life experiences. Making connections between what she knows and what she sees in the textbook
Student D	Making connections between what he learned in high school and what is presented in the class.	Making connections between what he learned in high school and what is presented in the class Making connections between physics concepts and real life experiences. Making connections between what he knows and what he sees in the textbook

Table 5.1. Students' ways of using pre-understanding at the beginning and end of the winter semester 2014

Students participated in fall study	Ways of using pre-understanding in learning new materials in the Phys1201 course. (pre-interview, at the beginning of the semester)	Ways of using pre-understanding in learning new materials in the Phys1201 course. (post-interview, at the end of the semester)
Student E	Making comparisons between what he learned in high school and what is presented in the class. Making connections between some physics concepts and real life situations.	Making comparisons between what she learned in high school and what is presented in the class. Making connections between what she knows and what she sees in the textbook Based on topics, making connections between some physics concepts and real life situations. Student uses her pre-understanding to solve physics problems.
Student F	Didn't learn physics in high school and wasn't able to make a connections between physics concepts and real life experiences.	Making connections between the examples provided by the instructor and his similar experiences Making connections between what he learns in the class and what he sees in the textbook Student uses his pre-understanding to solve physics problems.
Student G	Making connections between what she knows and what the professor says in the class.	Making comparisons between what she learned in high school and what is presented in the class. Making connections between what she knows and what she sees in the textbook Making connections between physics concepts and real life situations. Student uses her pre-understanding to solve physics problems.

Table 5.2 Students' ways of using pre-understanding at the beginning and end of the fall semester 2014

5.9 An Example of Expansion in Students' Horizon

We used the "relationship between force and motion" as an example of pre-conceptions formed prior to learning in the class due to experiences in the life world. We explored what interviewees thought about the "relationship between force and motion" at the beginning of the semester. During the post-interview we asked what they thought about the "relationship between force and motion" at the beginning of the semester and also asked about their present ideas about the relationship between these two concepts. Tables 5.3 and 5.4 show the answers provided in the pre- and post-interviews. All interviewees mentioned reflective writing as one of the activities that helped them move from their knowledge about these two concepts at the beginning of the semester to their present ideas. This shows that reflective writing activity helped these students expand their horizons during the semester.

As can be seen in Tables 5.3 and 5.4, before taking this course these students had a preconception of relationship between force and motion due to their experiences in the real world. In the pre-interview, Student A provided an example of pushing a car stuck and explained a causal relationship between force and motion. In this example, the student's understanding of the relationship between force and motion is not extended beyond his experiences. In the sense of the life world, the relationship between force and motion is not really wrong within this student's horizon. It is just not extended enough to make sense of the uniform motion in which there is no net force acting on the object. During the post-interview he explained that at the beginning of the semester he lacked the ability to make connections among physics concepts. By expanding his horizon and learning about Newton's laws he had a great understanding of uniform motion and accelerated motion and the relationship between force and motion in each case.

The expansion of horizon is also obvious by looking at the explanations provided by Student B. His pre-understanding of the relationship between force and motion was similar to Student A. In the post-interview he first explained the relationship between force and accelerations (Newton's second law) and used this relationship to explain accelerated motion and motion with zero acceleration.

Student C used one sentence to explain the relationship between force and motion in the pre-interview. In the post interview she confirmed her pre-understanding of the relationship between these two concepts before taking this course and provided an example: "*if I push a desk and so it moves.*" This shows that her pre-understanding formed due to her experiences in the life world. She explained her understanding of the relationship between force and motion at the end of the semester by providing an example and as can be seen in Table 5.3 it contained more details and differentiated between a uniform motion (no friction) and accelerated motion.

At the beginning of the semester, Student D believed that an agent was needed to create motion. As he explained in the post-interview, he lacked the ability to make a connection between physics concepts before taking this course. As you see in Table 5.3, at the end of the semester he was able to use Newton's second law to explain the relationship between force and motion.

As can be seen in Table 5.4, Student E's explanation of the relationship between force and motion is based on her observation and life experiences and her understanding is not extended beyond these. She believed that a force was necessary to keep an object moving and provided an example of a car that eventually stops if she doesn't push it.

Interviewee	Understanding of the relationship between force and motion before entering the course "Student's explanation in pre-interview, at the beginning of the semester"	Understanding of the relationship between force and motion after taking the course "Student's explanation in post-interview, at the end of the semester"
Student A	"Force causes motion… I need to exert a force on a car to be able to push it when it is stuck."	"Before I didn't know about uniform motion and accelerated motion. Now I can make a good connection between uniform motion and Newton's first law. I can also see the connection between Newton's second law and an accelerated motion. Before, I didn't consider various forces acing on the object but now I first try to draw a free body diagram and consider all the forces acting on the object. When we learned about Newton's laws I learned the accelerated motion and uniform motion better. For example it made more sense to have a zero net force in uniform motion."
Student B	"The applied force makes an object move."	"We need a force to change the motion. When there is a force then there is an acceleration and so we deal with an accelerated motion. But there is no force on an object moving with zero acceleration. There are lots of things behind this that we can talk about, but believe me I understood this chapter well."
Student C	"Force creates motion."	"Well I know a lot more now. There is no friction and you push someone and he keeps moving and then you need another force to stop him or when there is a continuous force on an object then there is an acceleration."
Student D	"Force, or applied force, you know, an agent that can push or pull an object. Motion is when an object is moving. There must be an agent to create motion."	"We need force to create motion. The relationships between these two concepts are well explained in Newton's laws. For example an object in motion stays in motion unless there is a kind of force put on it."

Table 5.3 Students' understanding of the relationship between force and motion at the beginning and end of the winter semester 2014

Interviewee	Understanding of the relationship between force and motion before entering the course “Student’s explanation in pre-interview, at the beginning of the semester”	Understanding of the relationship between force and motion after taking the course “Student’s explanation in post-interview, at the end of the semester”
Student E	“Force makes objects move. When the applied force is gone the object stops finally. If I push a car it starts moving but it stops finally. But if the driver starts the car then it keeps going since the engine provides the applied force.”	“We need a force to cause motion but we don’t need a force to keep moving. If I push my friend in hockey, he keeps moving since the friction is very small. We also have different kinds of motion. Uniform motion, accelerated motion. To have acceleration, we need to have a net force, but in a uniform motion the net force is zero.”
Student F	“Force is pushing and motion is moving. You push something and it moves.”	“Force is in Newton and is the result of pressure. Like applied force. I push you and the result of this pressure is force. Motion is the result of force. I push you and you move. If you don’t move then there is another force that is against your motion. Like friction. That is why we usually talk about a net force in physics.”
Student G	“An object in motion has speed. If a kind of force is exerted on an object, the speed will change.”	“I know more about force and motion now. A force can change the direction of motion and also the speed of an object. This is what Newton’s second law is about. The relationship between force and acceleration and there is an acceleration when the velocity changes.”

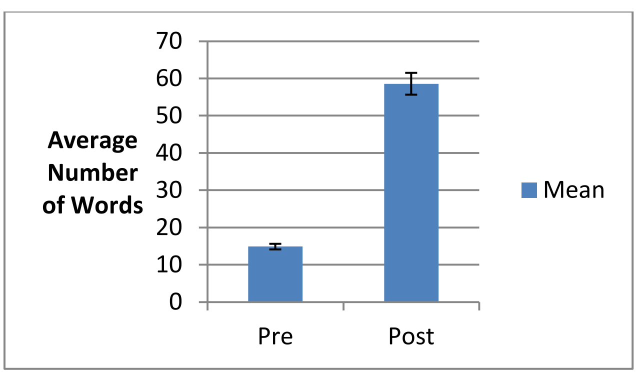
Table 5.4 Students’ understanding of the relationship between force and motion at the beginning and end of the fall semester 2014

In the post-interview I asked Student E about her understanding of the relationship between force and motion before taking Phys1201 course and then I asked her to explain her present ideas about the connection between these two concepts. In the post-interview she explained that a force causes motion but a force is not needed to keep an object in motion.

Even if Student F believed that he didn't use his pre-understanding and it was not easy for him to think about the application of the physics concepts in real life, he used his experience to explain the relationship between force and motion. In the pre-interview he said that he had no idea about the relationship between force and motion and I asked him to guess based on his experiences and observations. In the post-interview he was confident and provided examples to support his explanation.

In the pre-interview Student G explained that force influences the speed of an object. In the post-interview she talked about the influence of force on both magnitude and direction of velocity. She used Newton's second law to explain the relationship between force and motion in the post-interview.

As you see in Tables 5.3 and 5.4, at the beginning of the semester, all students had a preconception of relationship between force and motion due to their experiences in real life. They all provided a causal explanation to discuss the relationship between force and motion. However, at the end of the semester, interviewees were able to make comparison between uniform motion and accelerated motion. For example, at the beginning of the semester Student E believed that "when the applied force is gone the object will stop." However, at the end of the semester Student E explained that "in a uniform motion the net force is zero." At the end of the semester, interviewees were able to think about the relationship between force and motion in various kinds of motion (uniform motion and accelerated motion) instead of providing a causal relationship that works for all situations. Interviewees developed hypotheses based on their real life experiences at the beginning of the semester. Their explanations of the relationship between force and motion were formed prior to scientific reflection. What actually happened during the semester is not correction by science of a mistaken idea, but an extension of the situations that are not easily conceivable in real life. For example, the situation in which there is no friction and so an object keeps moving with constant velocity while the net force acting on the object is zero. This example (students' explanation of the relationship between force and motion at the beginning and end of the semester) suggests that all interviewees' experienced an expansion of their horizon during the semester. As a confirmation o this analysis, I counted the number of words used by interviewees to explain the relationship between force and motion in the pre- and post-interviews. The results presented in Figure 5.1 suggest that the interviewees who experienced an expansion of their horizons also had more to say about the relationship between force and motion. I am aware of the fact that "word count" is not always a good measure, but it is fine here due to the depth of analysis and considering the content of the arguments made..



Analysis	Pre-interview	Post-interview
Mean	19.86	58.57
N	7	7
Std. Deviation	14.064	20.329
Median	20.00	58.00
Std. Error of Mean	5.316	7.684

Figure 5.1: The number of words used by interviewees to explain the relationship between force and motion in the pre- and post-interviews

It is great to see that at the end of the semester interviewees had more to say about the relationship between force and motion and used other physics concepts such as acceleration and Newton's laws to support their explanations. The example provided in Table 5.3 and 5.4 shows the expansion of students' horizons during the semester. All interviewees except for Student F argued that they used their pre-understanding, going back and forth between their horizon and that of the textbook, making comparisons with and reasoning about the materials presented.

Reflective writing expands students' possibilities of using pre-understanding and helps them expand their horizons. We conducted an analysis of the interviewees' reflective writing products to see whether they were actually doing what they said they were doing in the interviews. Chapter 6 presents the analysis of interviewees' writing products. To determine if the experiences reported by these seven students were consistent with the experiences of more students in the group, I assessed the writing products of 41 students who were not interviewed. The results of this assessment are also discussed in Chapter 6.

Chapter 6: Students' Reflective Writing Products

In this chapter we reviewed the reflective writing products of each interviewee and also assessed the writing products of a randomly selected cohort of 41 students enrolled in Phys1201 course to learn if the experiences reported by these seven students were consistent with the experiences of more students in the group. We used the rubric (Appendix A) developed by Kalman et al. (2012) to analyze the reflective writing assignments. The analysis of the interviewees' reflective writing products helped us to confirm that they were actually doing what they said they were doing in the interviews.

6.1 Student A's Reflective Writing Products

As Student A mentioned in the pre-interview, he considered physics as a problem solving discipline and had a cook-book method to solve physics problems. To understand the definition of all words and terms used in the problems, he looked them up in his notes and if he didn't quite understand them then he tried to find the concepts on the internet. Since reading the textbook was not a part of his learning strategy he did not like the reflective writing assignments at the beginning of the semester. His first reflective writing assignment was just a summary of the main concepts. He didn't provide any examples and just copied the definition of the main concepts from his notes and the textbook. For example:

> "*Displacement is the change from the final point to the initial point. Displacement is also considered to be assigned quantity because it can be either positive or negative*" or his explanation of a uniform motion is: "*an object displaying a straight line on a position-versus-time graph is considered to be moving in uniform motion.*"

He did not explain what his understanding of these concepts is and just copied the definition of the main terms from his notes and the textbook to provide the first reflective writing assignment. He was not able to make a connection among the main concepts and as a result his first writing product contained 8 paragraphs. Two paragraphs contained three sentences and the remaining five paragraphs provided the definition of the main concepts in two sentences. He did not provide any example related to real life situations in his first writing product. The feedback provided to Student A motivated him to read the rubric and provide better writing products:

> "*When I wrote the first reflective writing assignment, I just wrote something to get a mark. When I received my mark, I was so surprised. I did not lose any marks for the concepts that I explained wrong. I checked the rubric and found it interesting. It is different. It wants you to find the key concepts and explain them in your own words. It wants you to provide some examples related to real life. I put too much effort on the second assignment. I found the key concepts, explained them in my own words. I tried to connect them to my life to provide good examples. I also found that there are some parts in the textbook that have not been covered in the class and can help me solve the assignments better*."

His second reflective writing assignment was improved in terms of clarity and he tried to connect the concepts of acceleration and velocity to his experience of driving. He provided four lengthy paragraphs and explained more than one concept in each that shows he was able to see the connections among various concepts. To explain an accelerated motion, he noted that gravitational acceleration is a constant acceleration that everyone experiences in life. It is interesting to see that he tried to interpret the concepts in the second assignment:

> "*The trickiest part about interpreting acceleration is that you cannot simply look at the slope of a velocity over time graph in order to tell the direction of the object like you could with velocity in a distance over time graph. For example if on your graph the slope is negative, however it is still in the positive portion of your graph, at first sight you may think that the object is slowing down. This is not the case. The object is simply speeding up at a slower rate. This is the case until the graph actually does have the velocity hit zero or turn into a negative number. At this point the direction of the object has in fact changed because now the velocity is headed in a negative (opposite) direction.*"

It was great to see an outstanding improvement from the first assignment to the second one. In spite of the fact that Student A tried to explain the concepts in his own words and provide real life examples to clarify the key principles, there is a lack of hermeneutical movement in some parts of his second assignment. I believe that he tried to provide an assignment based on his own understanding of concepts without trying to solve the conflicts between his own understanding and the materials presented in the textbook. In the pre-interview conducted after second labatorial , he explained the importance of a hermeneutical movement between his own understanding and the textbook: "*I try to compare what I know with what I see in the textbook. Because we need to explain the concepts in our own words we have to make sure what we get does not contradict what is written in the textbook,*" but his expression is inconsistent with his second reflective writing assignment. It was great to see that his writing style changed from a copy of the term definition to his own explanation of the concepts.

In the third reflective writing assignment Student A explained his understanding of the limitations and restriction of using projectile motion formulae in real life situations: "*for the purpose of giving real life examples, most of the time in this course we will pretend that air* *resistance is negligible in order to get an idea of what the object should do.*" Even though he explained the main concepts in his own words, he didn't use a reflective writing style to discuss the factors such as launching angle and initial velocity affecting a projectile motion. In the post-interview, Student A mentioned explaining as a part of his learning strategy: "*In my opinion I understand something when I can teach it or explain it. Reflective writing is like explaining materials*" and this is consistent with his writing products. However when a topic such as "projectile motion" contains many equations and formulas there is not enough effort in his writing assignments to explain the reasons behind each equation.

In his fourth reflective writing assignment about Newton's first law and forces, he made a good connection between the new concepts and the ones taught in the previous chapters. Beside the explanation of an example provided in the textbook, he talked about his experiences of gravitational force and driving to clarify Newton's first law. He used his own real world experiences to explain the main concepts such as friction:

> "*A good example of humans overcoming friction comes from waterslides. To go down a regular slide there is too much friction to allow your pants to slide down the inclined plane at a very fast speed. However when you run water down the inclined plane it reduces the amount of friction between you and the slide allowing you to travel down the slide much faster causing a much more exciting ride.*"

Many concepts related to Newton's second law were covered in this assignment. He used his explanation of gravitational acceleration provided in his previous assignment to explain the relationship between mass and weight. In his next assignment about Newton's second law, he provided a summary of the concepts presented in the textbook as well as his own understanding of them. I believe that when a topic was more sensible and easier to understand, Student A relied more on his own understanding and didn't make comparisons between what he got and the materials presented in the textbook. In contrast when the topic was sophisticated and less sensible, he provided a summary of the concepts as well as his own understanding of them and tried to make a comparison to make sure that his understanding agrees with the textbook.

Student A explained his own understanding of Newton's third law in reflective writing Assignment 6. He mentioned his own experiences of the real world to clarify Newton's third law:

> "*When a boxer punches a punching bag the boxers hand will get injured if the proper technique is not used. This is because however much force the boxer hits the punching bag with, the same amount of force is being pushed back onto the boxer's fist by the bag.*"

He has provided many examples related to real life situations to clarify this topic and made a great connection between Newton's third law and the concepts covered in the previous chapters such as Newton's second law and various types of forces.

Students A provided a summary of the definition of the main concepts to explain circular motion in reflective writing Assignment 7. He missed explaining some main concepts but provided many examples related to real life situations. From his writing assignment, I conclude that he constructed his own understanding of concepts that were related to the principle covered in the previous chapters such as centripetal acceleration and centripetal force. He used his pre-understanding and made comparison to explain such concepts. In contrast, he failed to provide a clear explanation of the new concepts such as frequency and as a result copied the definitions presented in the textbook or completely ignored them.

He used a reflective writing style to explain his understanding of energy and provided many examples based on his own experiences. He was aware of the difference between the meaning of the terms “energy” and “work” that we use in real world with what they actually mean in physics world. The comparisons that he made between his own understanding and the definitions presented in the textbook, show that he approached this topic in the manner of hermeneutics. There are equations and formulas written in the first assignments with a brief explanation of their applications. By the end of the semester Student A was able to explain his own understanding of the equations and formulas and provided real life examples to clarify their real life applications:

> “*Momentum is known as the mass in motion. Basically, when an object is moving then it has momentum since it has mass. The amount of momentum depends on two things, one the mass of the object, and two the velocity of an object. If a collision occurs between object A and B (in an isolated system), the total momentum of the two objects before the collision is equal to the total momentum of the two objects after the collision. But if you consider just object A as your system, then its momentum is not conserved since its velocity has changed after the collision. An example of conservation of momentum would be two balls colliding into each other in a game of pool. For example white ball collides into ball 1. The total momentum of the two balls before the collision is equal to the total momentum of the two objects after the collision when there is no external force acting on the system of two balls. But if you consider white ball as your system, then its momentum has changed. The external force from ball 1 on the white ball changed its momentum.*

This example explains the equation that shows the relationship between external force and momentum."

Reflective writing activity Assignment 9 is the shortest reflective writing assignment done by Student A, since he explained the concept of momentum and conservation of momentum in Assignment 8. Table 3 shows an evaluation of Student A's reflective writing products based on the rubric provided (Appendix A). The reflective writing activity is worth 20 percent of the labatorial final mark. The sum of all points in Table 6.1 is 20 for each reflective writing activity. If there is no conflict between the student's explanation and the materials in the book, the last marking feature is not applicable and each feature of the rubric is worth 5 points. If student's explanation is in conflict with the materials presented in the textbook and student is not able to identify the inconsistency, then the last feature is applicable and as a result each marking feature is worth 4 points.

As can be seen in Table 6.1, except for reflective writing Assignment 6 Student A didn't identify any conflict between the materials presented in the textbook with his own ideas. In most reflective writing products, he provided a summary of the topics presented in the textbook and then explained his own understanding of them. Similarly, I didn't find any major conflict between his explanations and the materials presented in the textbook.

In the post-interview he emphasized that he compared his own understanding of materials with the ideas in the textbook to solve the conflicts: "*When you know about something and you read about it then you make comparisons and it makes you think deeply about it and you gain a better understanding I think.*" He also shared one of his experiences of facing a conflict:

> "*I thought that normal force and weight are action and reaction forces in Newton's third law. It is written in the textbook that action and reaction have the same magnitude, but I had solved some problems that weight and normal force had different magnitudes. On the other hand the textbook says that action and reaction never cancel each other and so that confused me a lot. I decided to read those pages over and over and then found that action is from A to B and reaction from B to A and so I found that I have been thinking about two different forces acting on one object. It took a while but by drawing a free body diagram and reading the section of Newton's third law over and over, I could figure out what was going on.*"

In summary, based on the pre- and post-interviews with Student A, I conclude that this student displayed clear characteristics that align with a student who highly values the reflective writing exercise, and as such clearly developed his reflective writing skills over the course of the term, while simultaneously improving his physics understanding. These conclusions are supported by Student A's statements in the pre- and post-interview and his reflective writing products. Students A's extensive use of life experiences to explain the physics concepts in his reflective writing assignments is consistent with what he actually said in the interviews.

In general, Students A's performance was related to the topic of the writing assignments and the concepts contained in each assignment. A comparison between Student A's explanation of the same concepts at the beginning and the end of the semester reveals that Student A's horizon expanded during the semester.

Points/ **Features present in the reflective writing product**	**RW 1**	**RW 2**	**RW 3**	**RW 4**	**RW 5**	**RW 6**	**RW 7**	**RW 8**	**RW 9**
A fluent piece of work in the student's own words	0	4/5	3/5	5/5	3/5	4/4	1/5	5/5	5/5
Student explains all key concepts from assigned reading and lecture in his or her own words	0	5/5	1/5	5/5	5/5	4/4	1/5	5/5	3/5
Student relates recently introduced key concepts to previously studied concepts	0	5/5	1/5	5/5	5/5	4/4	1/5	4/5	4/5
Student relates key concepts to his/her own life experiences	0	5/5	1/5	5/5	5/5	4/4	2/5	5/5	5/5
Student identifies that the ideas/facts/data **(If applicable) presented in the textbook are in conflict with the students' own ideas**	0	N/A	N/A	N/A	N/A	4/4	N/A	N/A	N/A

Table 6.1 Evaluation of interviewee A's Reflective Writing (RW) products based on the rubric provided to the students (Appendix A)

6.2 Student B's Reflective Writing Products

In both pre- and post-interviews, Student B mentioned that he considered physics as a problem-solving course. This is confirmed in his reflective writing assignments. For instance he provided a separate paragraph in his first writing assignment to explain the application of units in solving problems or discussed the equations provided in Chapter 2 to solve the problems:

> "*What is the use of displacement, velocity, acceleration, time in separate equations if a physics problem requires the use of all terms? There are three types of equations that are used when constant acceleration in a problem is mentioned, either implicitly or directly. There is a formula that doesn't require time, another one that doesn't require final velocity and lastly, a formula not needing the change in displacement. To measure for acceleration, the change in velocity over the change of time is used. These equations are used quite often in solving physics questions.*"

The pre-interview was conducted after Student B received feedback on his first reflective writing assignment. He explained the way he provided his first reflective writing: "*First I found the main principles and provided a list of them. Then I looked at the definition of each principle in my notes and textbook. Then I wrote down what I got.*"

He covered all of the main concepts in his first reflective writing product and figured out the conflicts between his pre-understanding and the ideas presented in the textbook. For instance, he thought the distance travelled is the same as displacement and also believed that average velocity and speed are the same concepts. By reading the textbook he realized the differences between these concepts and provided some examples to explain what he gained by reading the textbook:

“*With distance travelled not having an assigned direction, someone could possibly travel a distance of 1000km, but yet have less displacement from the origin than that of someone who only moved 1m. This would be possible as long as the person who travelled the 1000km were to change direction and end up within 1m of the original location.*”

When Student B explained units in his first writing assignment, it was interesting to see that he tried to think ahead and explore the relationship between what he learned in the first chapter with what would be covered in the course later: “*I am excited to see how we can relate units of distance and time to other units such as force or pressure.*” The real world examples provided in his first reflective writing confirmed what he mentioned in his pre-interview about the application of familiar physics principles in the real world: “*It was easy to find the application of the theoretical principles in real life. We are involved in motion, velocity and acceleration every day. I’m not sure it will be easy when we deal with more complicated principles later on in the course.*” He had a concern about relating topics that are not familiar to real world situations.

Student B provided his own explanation of acceleration in his second writing product as well as what was presented in the textbook. There was no conflict between his understanding and the definition of acceleration in the textbook. He mentioned that he didn’t know how to find the direction of acceleration. He provided an example of throwing a ball up and watching it fall down to explain the direction of acceleration, but his argument was in conflict with what was presented in the textbook and he didn’t realize that. He explained how to find the direction of acceleration using the velocity versus time graph, but didn’t go back to the example of the ball to investigate his argument about the direction of acceleration. As discussed before, at the beginning of the semester he looked for the terms in the textbook to get the basic knowledge to be able to solve the problems but after getting feedback on the first two assignments he decided to combine reading and thinking to make sense of the concepts. Although he used reasoning to provide a definition of the main concepts in his second assignment, the lack of reasoning and comparison is obvious when he tried to explain the direction of acceleration in accelerated motion.

Student B used his lecture notes as well as the textbook in writing the third assignment. It is interesting to see that he had no problem finding the direction of acceleration in this assignment. In the previous assignment he believed that if an object is moving up then it would experience a positive acceleration and a negative acceleration is associated with an object moving downward. His explanation of acceleration in the third assignment shows that he gained a better understanding of the direction of acceleration and there is no conflict between his understandings of the acceleration in a projectile and the example of a ball going up and down with what presented in the textbook. What helped him to figure out the direction of gravitational acceleration were the assignment and the textbook problems in which he had to find the sign (positive or negative) of gravitational acceleration (g). He referred to his notes and the textbook to find out the direction of the gravitational acceleration in various situations. He provided a good understanding of the equations related to a projectile's motion. He broke down projectile motion into a uniform motion along the x-axis and an accelerated motion along the y-axis and related them to the chapters covered previously. As he explained in the post-interview, when he can use the physics concepts in problem solving, he can claim that he gained a good understanding of them. His statement is consistent with his writing products during the semester.

Even if he provided a good explanation of the main concepts in his own words, some important points are summarized in the third writing assignment:

> "*it is good to keep in mind some key points regarding projectile motion like at the top of the projectile[‘s trajectory], speed is zero for a brief moment, the initial speed of an object will return with the same speed (symmetry analysis), and that the launch angle will cover the same distance if the addition of two numbers equal ninety degrees.*"

A part of the motivation to do reflective writing is to have students think and try to explain the reasons behind such key points. Even if Student B tried to make sense of the main concepts through reasoning, he failed to explain the reasons behind some key points specially the equations and formulas.

In the fourth reflective writing assignment about Newton's first law, he formulated some questions such as "*what causes a ball to keep rolling after being pushed?*" or "*what is the natural state of any object?*" or "*why doesn't objects continue their natural state?*" and tried to compare what he thought about those questions with what he saw in the textbook. He provided a simple example to support his understanding of an object's natural state:

> "*the natural state is when an object is not affected by anything else, such as air resistance or friction. For example, if I pushed my ball at 0.5 meters per second, it should continue at that velocity forever, and if my ball is at a velocity of zero or rest, it will remain at rest forever" and then explained that his understanding is consistent with the textbook's definition of a Newton's first law: "Consider an object with no force acting on it. If it is at rest, it will remain at rest; if it is moving, it will continue to move in a straight line at a constant speed.*"

He started the fifth reflective writing assignment about Newton’s second law and forces by providing an example:

> “*It’s a cold winter day, and my car won’t turn on to get me home. My best friend suggests that he’ll push the car to get it moving. The push that my best friend is applying is a force. The push or pull of an object to another object was one of the definitions mentioned for force*”

He manipulated the same example to explain other concepts such as Newton’s second law:

> “*If my best friend and I were to push on the car together, there would be twice the amount of force applied on the car. Once the car gets moving, the car is speeding up. Hence, it is accelerating. If applying a force creates acceleration on the object, there is a relation between the two.*”

The expansion of his horizon is obvious in this writing product. For instance he knew that by applying more force on an object, it will accelerate more, but he didn’t know about the relationship between mass and acceleration:

> “*I recall the second law as when a force is applied to an object, the object will accelerate. Force and acceleration are directly proportional to each other. If one increases, the other one will too. I didn’t remember that mass could have a relationship too with force.*”

What he recalled of the concept of force was just a push or pull on the object, but by reading the textbook he found that force is a vector quantity and could use what he learned in the first chapter about vectors in this topic. As he mentioned in the post-interview, he used his own reasoning in this assignment to make sense of the materials presented:

> "*What is equilibrium I asked myself when I first saw the title of this section of the textbook. Even after reading this passage once then having to write about it, all I got out of it was acceleration equals zero, which didn't connect in my mind with the world equilibrium.*"

In the sixth reflective writing assignment he made a good connection between Newton's third law and Newton's second. He was able to identify the conflicts between his pre-understanding and what he read. He addressed these conflicts by reading the assigned sections over and over and thinking about his own experiences of Newton's third law.

Although most students were not able to provide a writing assignment with a reflective writing style to explain circular motion, Student B's seventh writing product is the best example of a reflective writing assignment. Even if he had concerns about providing real word examples related to unfamiliar concepts, he started his seventh assignment with a great story from when he was a child:

> "*When I was little, my friends and I would play Ring Around the Rosie. One of us loved the thrill of going faster and faster until we let go of each other and would fall down. I didn't know at the time that we were examples of Physics in action, specifically Circular Motion. Like in uniform motion, my friends and I were travelling a certain distance over a certain amount of time, but unlike uniform motion, we were travelling in a circle instead of a line. When my friend decided to go faster, we would cover more distance over a shorter amount of time.*"

There is a back and forth movement between the circular motion topic and the first chapter that contains accelerated and uniform motion in this assignment. Student B tried to find the similarities between circular motions with the motions covered previously in the course, at the same time looking for a real world situation to clarify what each concept means. This confirms his attempt to make sense of the materials presented: "*I tried to find out the reason behind each concept and so my understanding is not just a collection of words and terms. There are meanings behind each.*"

There are many equations presented in the chapter of momentum, work and energy in the textbook and many students had difficulties discovering the meaning behind each formula. However, Student B explained the meaning of the equations in his own words and provided examples to clarify them. In reflective writing Assignments 8 and 9 his explanation of some concepts such as momentum, work, kinetic energy and potential energy resembles a summary of the textbook. However, he has provided some examples to construct his own understanding of these concepts: "*Lifting an apple from the ground has something in common with a campfire. What could this similarity be? They both transfer energy from one form to another form.*" Although reflective writing Assignment 9 shows that Student B approached the text in the manner of hermeneutics, he did not relate the key concepts of this assignment to the ones previously taught.

He wrote all reflective writing assignments in first person and tried to make connections among various physics concepts. There is no main concept missing in his writing assignments and the explanations and examples provided show that he spent a great deal of time making sense of the materials and thought deeply about the ideas presented in the textbook. Student B's writing products contain many paragraphs. There is a main concept explained thoroughly in each paragraph. This is consistent with the way of doing reflective writing that he explained in the post-interview:

> "*I prefer to read a short section and then I understand it well then I move on to the next section. I divided the long sections to small parts actually. I read each section first and try to write down what I understand about that part on a piece of paper*."

There is a hermeneutical movement in each section of Student B's reflective writing products where he compared his own understanding with the ideas presented in the textbook: "*To be honest I didn't close the textbook as was mentioned in the lab outline. I needed to have the text in front of me to be able to compare what I write with what I read right away.*" It was interesting to see that Student B formulated many questions in his writing products and tried to use his reasoning to address those questions. For instance, to relate Newton's third law to Newton's second law he formulated the question: "*The ground is not really moving backwards as the ball is moving forwards. Or at least so I thought. When I reread the textbook again, the ground is moving but to a very small amount. Why?*" The questions formulated by Student B agree with his statement in the post-interview:

> "*When I was trying to make sense of what I read I asked myself some basic questions: what, where, when, why, and how. And then I tried to think of the application of that concept in real life. As I said before I thought about hockey when I was reading about uniform motion.*"

Table 6.2 shows an evaluation of Student B's reflective writing products based on the rubric provided (Appendix A).

In summary, based on the pre- and post-interviews with Student B, this student displayed clear characteristics that align with a student who highly values the reflective writing exercise, and as such clearly developed his reflective writing skills over the course of the term, while simultaneously improving his understanding of physics. These conclusions are supported by Student B's statements in the pre- and post-interview and his reflective writing products. Student B tried to make sense of the principles and equations in the textbook and provided real life examples to clarify his understanding of the concepts presented in the textbook. His writing assignments confirm that he had a hermeneutical approach while providing his writing activities, and his general improvement in explaining the concepts and equations confirms an expansion in Student B's horizon during the semester.

6.3 Student C's Reflective Writing Products

In the pre-interview Student C classified the contents of her pre-understanding into two main categories: what she learned in high school and her real life experiences. She believed that she couldn't rely on real life experiences since the materials in the textbook are related to ideal situations while we live in a real non-ideal world. Her ideas about real life situations are obvious in her first writing product: "*It is not likely that an object will travel at a constant velocity for the entire time that it is moving.*" She provided some examples related to the concepts of position and displacement but failed to relate the concept of uniform motion to a real life experience. Her first writing assignment starts with a brief summary of the concepts that she aimed to explain and then an explanation of the main concepts in her own words is provided.

Points **Features present in the reflective writing product**	**RW 1**	**RW 2**	**RW 3**	**RW 4**	**RW 5**	**RW 6**	**RW 7**	**RW 8**	**RW 9**
A fluent piece of work in the student's own words	3	4	5	4	5	4	4	5	4
Student explains all key concepts in his or her own words	5	4	3	4	5	4	4	3	4
Student relates recently introduced key concepts to previously studied concepts	5	4	5	4	5	4	4	3	2
Student relates key concepts to his/her own life experiences	5	4	5	4	5	4	4	5	4
Student identifies that the ideas/facts/data **(If applicable) presented in the textbook are in conflict with the students' own ideas**	N/A	2	N/A	4	N/A	4	4	N/A	4

Table 6.2 Evaluation of interviewee B's Reflective Writing (RW) products based on the rubric provided to the students (Appendix A)

Student C's first writing assignment ends with a summary of the position-versus-time and velocity-versus-time graphs. She didn't explain what they actually mean and didn't provide any example to explain what information she can get using these graphs. In the pre-interview she explained how she wrote her first reflective writing assignment:

> "*I read the lab outline and the instructions provided. First I skim the sections quickly and then start reading one specific topic. Then I write about it and provide an example. There are usually some examples in the textbook that help me come up with a good example. When I'm done, I read it at least two times to make sure that I haven't missed a concept.*"

As she said all main concepts are covered in her first writing assignment, however some main concepts such as a uniform motion are not supported by real life examples. This might be due to the fact that she had trouble relating some materials in the textbook to the real life situations.

Student C believed that we live in an ideal world different from what the textbook explains. This point of view is also obvious in her second writing assignment where she tried to define acceleration: "*Acceleration is the change in an object's velocity in a given time frame, and although it is realistic for an object to speed up and slow down when moving.*" Since change in velocity seems realistic to her, she could provide some examples of driving to clarify an accelerated motion. Again, she provided a brief summary of the concepts she intended to explain in her second writing product and the ones covered in the previous chapter. This shows that she tried to make a relationship between the new concepts and the one covered previously. In one paragraph she confused the concept of uniform motion with a motion in which the acceleration is constant: "*We can also find acceleration by looking at a velocity-versus-time graph. Since the object would be considered as moving at a constant velocity, the graph would have a straight line with a positive slope.*" If an object is moving with a constant velocity then it is a uniform motion and as a result there is no acceleration and hence the velocity-versus-time graph is a horizontal line with a zero slope. As I explained before, in the first writing product she provided a summary of the graphs without explaining what they actually mean and the misunderstanding of the graphs is obvious in her second writing assignment. Her explanation of the graphs in an accelerated motion is a summary of an example provided in the textbook:

> "*When an object is in constant acceleration, as previously noted, the velocity vs. time graph will be a straight line with a positive slope, a parabola would be created in a position vs. time graph, and in an acceleration vs. time graph, there would simply be a straight horizontal line.*"

The term "positive slope" is about a particular example of an accelerated motion in the textbook that she summarized in her writing product. This obviously shows that Student C did not figure out what the graphs actually mean and what information she can get by looking at them. In the last paragraph, Student C explained what a positive or negative acceleration means. She provided a good explanation of her understanding of the sign of acceleration, but she failed to explain the same concept using the position-versus-time and velocity-versus-time graphs.

The third writing assignment about the projectile motion looks like a summary of the concepts presented in the textbook. However, it is interesting to see that Student C started to realize the limitations of using physics principles to explain real life situations:

"If I were sitting at a table and I happened to knock my calculator off of the table with my elbow, the motion of my calculator falling from the edge of the table onto the floor would be considered free fall. If I accidently were to push a piece of loose-leaf paper off of the edge of my table, while falling from the table to the floor, both gravity and air resistance would be acting on the paper, causing it to float around a little bit, and we can say that the paper is not in free fall."

This is a big step for a student who believed that physics principles explain ideal situations rather than actual non-ideal real life experiences. Even if she tried to explain the projectile motion in her own words, she failed to make sense of the equations provided in this chapter of the textbook such as the ones used to find out the range, the time of flight and the maximum height that an object can reach. She explained that a projectile motion can be broken up into two components, but failed to relate each component to what she learned in the previous chapters. Her third writing assignment looks like a work that had to be done. It lacks student's thinking and reasoning of what the concepts actually mean.

The fourth reflective writing product provides a summary of Newton's first and second laws. However the examples provided to clarify Newton's second law show that Student C understood this topic well. However, the definition of natural state and what Newton's first law is about were summarized from the textbook. There is no example provided to explain what Newton's first law means. I believe it might be due to the fact that it was hard for Student C to find an example of Newton's first law in real life. Her explanation of Newton's first law contains an ideal situation in which there is no force acting on the object:

> “*If there is no force acting on a particular object, the object will stay at rest and if it is moving, it will keep going at the same speed along a straight line. However, there will always be some external forces involved when looking at an object’s motion.*”

Even if she provided a summary of the concepts covered previously, she didn’t relate them to the new concepts in this writing assignment. The example provided to clarify Newton’s second law is the explanation of a numerical example provided in the textbook. As she explained in her pre-interview, the examples provided in the textbook helped her think about the situations related to the concepts and in this assignment the numerical example provided in the textbook inspired her to explain it in her own words: “*There are usually some examples in the textbook that help me come up with a good example.*” The assignment ends with student’s methodology to solve the problems related to Newton’s second law.

Student C explained her own experience of pushing a chair to clarify Newton’s second law in the fifth writing assignment. Clear explanations of the main concepts and the relationship among them suggest that Student C spent a great deal of time thinking about the concepts and explaining them in her own words in this assignment. She also provided a real-world example to explain Newton’s first law and its relationship to the second law. This assignment confirms what she said in the post-interview: “*To be honest I didn’t take the course seriously and I just wanted to pass it but after the first midterm I realized I would have to work hard to pass it.*” She emphasized that the way of doing reflective writing changed after the first midterm exam and she started to actually think about the meaning of the concepts presented in the textbook. The writing product about Newton’s second law has a reflective writing style and truly reflects the student’s reasoning of the concepts.

Student C summarized the textbook's explanation of Newton's third law in the sixth writing assignment followed by her own understanding and real-world experiences. She compared the textbook's explanation with her own understanding and experiences and didn't find any conflict. The relationship between Newton's third law and second law is well argued in this assignment. In the textbook, there is an example of walking to clarify Newton's third law. It explains that when you are walking, you push backwards on the ground and the ground pushes forwards on you. These two pushing forces are the result of the friction force between the sole of your shoe and the ground. When you take a step forwards the sole of your shoe pushes backwards on the ground. By Newton's Third Law the ground pushes forwards on the sole of your shoe. It is this frictional push from the ground that enables you to move forwards. Walking would be impossible without this force of friction, between the ground and the sole of your shoe, pushing on you. Student C was inspired by this example and explained the role of Newton's third law in riding a bicycle. It is obvious that she gained a good understanding of the example provided in the textbook and was able to use the same principle to explain a slightly different phenomenon. As she stated in the pre-interview, the textbook examples helped her think about the similar situations and come up with great examples related to real-world situations.

There are many equations provided in the chapter about circular motion. Since Student C considered physics as a problem-solving course, she explained the ways of using these equations in problem solving. For instance she didn't explain what "angular position" meant, but explained the ways to find an object's angular position:

> "*If we want to know the angular position of the object from the circle with a fixed radius, we first need to find the angle measuring from the x-axis. If measured clockwise of the x-axis, the angle will be negative; if measure counter clockwise, the angle will be positive.*

However, the units we use are radians rather than degrees. We can also find the angular position of an object by using the arc length and radius."

She described the way of calculating angular velocity in a circular motion without explaining what this concept actually means. There is one sentence provided by Student C about the relationship between circular motion and linear motion, but there is no further explanation to discuss the similarities: "*Uniform circular motion and linear motion have a lot of similarities.*" Student C provided some examples related to real life to discuss the ways of calculating various quantities in a circular motion.

The reflective writing assignment about work and energy done by Student C has a reflective writing style. She started the assignment by a real-world example:

> "*When my dad plays pool, he is providing an example of the law of conservation of energy. We know that energy cannot be created or destroyed, but it can be transferred. We can say that the pool table is the system, and when my dad hits the cue ball, his ball will move, having work done on it, and the ball will hit the other balls on the cue table. This causes the other balls to change some of their energy and have kinetic energy.*"

This example was followed by the student's understandings of the concepts of energy and work. She also provided an example about a skater to explain kinetic and potential energies. Various kinds of energies are well discussed in the student's own words. All main concepts are covered in this assignment and there is no major conflict between student's own understandings and the materials presented in the textbook. Student C didn't do the last assignment on the conservation of momentum and collisions in one dimension.

As she explained in the post-interview, she took the course more seriously after the first mid-term exam and a general improvement in her writing products confirms this fact. One of the main concerns of Student C at the beginning of the semester was relating the physics concepts explaining the ideal situations to the real life situations. For instance she was not able to find a real example about uniform motion. However, there are many examples provided in the last writing assignments that were deeply discussed by Student C. In the post-interview she mentioned that providing examples in the reflective writing assignments helped her visualize the physics principles and understand them better. We talked about Student C's way of preparing reflective writing assignments at the beginning of the semester. In the post-interview, the strategy of doing reflective writing assignment explained by Student C contained thinking and reasoning:

> "*Well I would read each section slowly and then I tried to think about what I read and tried to explain them. When I could explain the concepts to myself I was able to write them down. I also thought about their application in life and so provided real examples.*"

Table 6.3 shows an evaluation of Student C's reflective writing products based on the rubric provided (appendix A).

As you see in Table 6.3, Student C didn't identify any conflict between the materials presented in the textbook with her own ideas. In the first two assignments there are some conflicts between Student C's own ideas about the position-versus-time and velocity-versus-time graphs with the explanations of these graphs presented in the textbook. Student C couldn't identify these conflicts in her first two writing assignments. In general, her writing products were improved during the semester.

In summary, based on the pre- and post-interviews with Student C, this student valued the reflective writing exercise and used reflective writing as an effective learning tool to improve her understanding of the materials after the first midterm exam. These conclusions are supported by Student C's statements in the pre- and post-interview and her reflective writing products. Student C's first assignments lack reasoning, thinking and comparison. Her last 5 assignments confirm that she actually started making sense of the concepts and thinking about their applications in real life. She also started engaging her own experiences with the materials presented and made comparison between her understanding and what she saw in the textbook. Student C's explanation of the same concepts at the beginning and the end of the semester shows an expansion in her horizon during the semester.

6.4 Student D's Reflective Writing Products

In the pre-interview, Student D explained that preparing a summary is a part of his learning strategy and especially when he studies physics and mathematics, he needs to have a pen and paper to draw pictures and write a summary of concepts. Student D wrote his reflective writing assignments in first person.

His first writing assignment reflects his own understanding of the concepts: "*when I think of position, I think of the area in which something is located. But a position isn't just something's location but that location at a certain and specific time era.*" He explained the concepts of position, displacement, distance, speed, velocity and time separately and then related these concepts to each other to explain the meaning of velocity, speed, and uniform motion.

Points Features present in the reflective writing product	RW 1	RW 2	RW 3	RW 4	RW 5	RW 6	RW 7	RW 8	RW 9
A fluent piece of work in the student's own words	2/4	2/4	2/5	3/5	5/5	5/5	4/5	5/5	N/A
Student explains all key concepts from assigned reading and lecture in his or her own words	2/4	2/4	1/5	3/5	5/5	5/5	2/5	5/5	N/A
Student relates recently introduced key concepts to previously studied concepts	0/4	2/4	2/5	2/5	5/5	5/5	2/5	5/5	N/A
Student relates key concepts to his/her own life experiences	0	2/4	5/5	1/5	5/5	5/5	4/5	5/5	N/A
Student identifies that the ideas/facts/data (If applicable) presented in the textbook are in conflict with the students' own ideas	1/4	1/4	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 6.3 Evaluation of interviewee C's Reflective Writing (RW) products based on the rubric provided to the students (Appendix A)

In the second writing assignment he used a reflective writing style to explain the main concepts. He experienced the expansion of his horizon and learned more about the concepts:

> "*To me I thought acceleration to be how fast a car can go from 0 to 60 seconds or how fast you can get up to a certain speed. After reading the assigned pages, I have come to the conclusion that acceleration is the change in velocity over the change in time.*"

Even if students are not supposed to write down equations in their writing assignments, he wrote down three equations and tried to explain what he gained from each. It was interesting to see the student's interpretation of the equations. He also talked about his strategies to solve a problem:

> "*Problem solving is an important strategy when it comes to physics questions. First you need to Prepare, then solve and then assess the question to make sure it was done correctly. Preparing a question can involve drawing a picture to visualize the question, collecting and writing down all the necessary information in the question and doing some preliminary calculations which helps your conceptualize the questions that are going on.*"

As he mentioned in his interviews he considered physics as a problem solving discipline. This point of view is obvious in the numerical examples that he provided: "*a Subaru WRX is at rest at a traffic light. When the light suddenly turns green he begins to accelerate at 6.5 m/s2. How many seconds after the light turns green does he reach the speed of 60 m/s. Answer: (9.2 seconds)*".

The writing assignment about the projectile motion is a summary of the related sections of the textbook. There is a list of the equations with student's explanations needed to discuss a projectile motion. Again, he explained his ways of solving problems in this assignment:

> "*There are special ways to solving projectile motion problems that make it easier to visualize and set up so when working with the problem there is no confusion. Always draw an overview of the question and label all the parts make sure to write down all the components given to you and what you are trying to find. There are two types of kinematic equations one is for the vertical and the other is for the horizontal but all you have to do is make acceleration equal 0 in the vertical to get the horizontal equations.*"

A summary of the main concepts as well as student's own understanding are presented in reflective writing Assignments 4 and 5 about Newton's first and second laws. Most examples are numerical and the strategies of solving problems are emphasized:

> "*On the moon an astronaut jumps 2 feet straight up, despite the weight of his space suit which weighs 370 on earth. On the moon he and his suit together weighed only 90 pounds with g = 1.6 m/s2.*" The explanations of equations are clearer and there are examples provided to clarify the formulas: "*The Newton's second law equation shows that the acceleration vector points in the same direction as the net force vector. When several forces act on an object, we have to watch and make sure not to think that the strongest force will overcome all the other forces because it will not. It is the net force or the sum of all forces. Forces are vectors and we need to add them using vector rules. So the force in the Newton's law equation is the net external force and acceleration has the direction of this net force.*"

Student D also explained the unit of force based on the Newton's second law formula in reflective writing 5.

He started the writing assignment about Newton's third law by explaining the importance of free body diagrams and his own understanding of this part of the textbook followed by a numerical example:

> "*An example would be $F_{hammer\ on\ nail}$ to $F_{nail\ on\ hammer,}$ which are force pairs. A great example would be 2 kg hammer you hit a nail with 10 N. The hit gives the nail (mass 0.01 kg) an initial acceleration of 1 m/s^2. What is the magnitude of the force exerted on the hammer by the nail? The answer would be 10N as explained before force pairs will have the same magnitude in opposite directions.*"

In reflective writing Assignment 7 about circular motion he explained the equations and formula in words. Some concepts were well interpreted by this student:

> "*Like when you are listening to CD's and or watching a DVD there is a laser that is spinning in the circle reading it and you can tell its frequency by counting how many times it makes a full revolution in a certain amount of time (seconds)*".

However there were some main concepts missing or some copied from the textbook.

Student D presented a good understanding of the systems and conservation of energy in writing Assignment 8, but used a summary writing style to explain the concepts of kinetic energy, potential energy, thermal energy, and work. This assignment contains both summary writing and reflective writing styles. Student D didn't do the last writing assignment.

Student D's effort to make sense of the concepts and find the relationships between them is consistent with his explanations of his study strategy for this course:

> "*Reading the textbook before and after each class, asking questions, understanding the concepts behind the equations, trying to write down what the principles mean and providing some examples related to the real world, thinking about similar situations and trying to make sense of what I read and hear in the class*"

He explained the way he prepared his writing products:

> "*I did it paragraph by paragraph. I read a paragraph first and tried to understand the materials covered in that paragraph. Then I wrote down what I understood just like explaining the material to a friend. I also provided some real world examples related to the main principles. I tried to think about all possible situations that a principle could be applied.*"

Table 6.4 shows an evaluation of Student D's reflective writing products based on the rubric provided (appendix A).

As can be seen in Table 6.4, Student D didn't identify any conflict between the materials presented in the textbook with his own ideas. I also didn't find any conflict between his writing products and the materials presented in the textbook. In general his writing assignments are shorter than the assignments of Students A, B, and C. He tried to explain the main concepts briefly in his own words and discussed in detail the ways of using equations and formula in solving problems.

In summary, based on the pre- and post-interviews with Student D, this student displayed clear characteristics that align with a student who highly values the reflective writing activity.

This conclusion is supported by Student D's statements in the pre- and post-interview and his reflective writing products. Similar to other interviewees, Student D's style of writing depends on the topic of the assignment. His improvement in explaining the equations and diagrams in words, confirms that Student D's horizon expanded during the semester.

6.5 Student E's Reflective Writing Products

In the pre-interview, Student E emphasized that physics is about solving problems. The numerical examples provided in her writing products confirms that Student E considered physics as a problem-solving discipline and tried to explain the meaning of concepts by solving some sample problems in the writing assignments. Her explanations of concepts in the first assignments are vague, but her writing products became clearer by the end of semester. For instance, in the first writing assignment her explanation of speed and velocity is unclear and confusing:

> "*The word distance can be easily confused with an object's movement or place they are moving to. When in reality it means the amount of area an object can cover. The word displacement can come across as confusing and different to distance when you start to really try and define it. To keep this simple I would simply state that displacement is the number of km (or other certain measurement of distance) from where you started.*"

There is misuse of terms and words that results in seriously ambiguous explanations in the first assignments. For instance Student E kept using the term "area" to explain speed, velocity, distance, displacement, and uniform motion.

Points Features present in the reflective writing product	RW 1	RW 2	RW 3	RW 4	RW 5	RW 6	RW 7	RW 8	RW 9
A fluent piece of work in the student's own words	3	3	1	4	4	5	2	5	N/A
Student explains all key concepts from assigned reading and lecture in his or her own words	5	5	2	4	5	5	2	3	N/A
Student relates recently introduced key concepts to previously studied concepts	0	3	2	4	5	4	1	4	N/A
Student relates key concepts to his/her own life experiences	5	5	2	5	5	5	3	5	N/A
Student identifies that the ideas/facts/data (If applicable) presented in the textbook are in conflict with the students' own ideas	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 6.4 Evaluation of interviewee D's Reflective Writing (RW) products based on the rubric provided to the students (Appendix A)

In the second assignment, the student's explanation of acceleration is not different from her explanation of velocity in reflective writing assignment 1: "*The concept of acceleration can be defined as how fast an object is moving at a specific interval of time.*" She didn't relate change in magnitude or direction of velocity to acceleration. She again solved a problem to explain the concept of acceleration instead of providing an example related to her own experiences of speed and acceleration.

Student E started her third writing assignment by explaining uniform motion and accelerated motion that were the topics of the first two assignments. She provided a clear explanation of these two concepts and then tried to compare them with projectile motion that was the topic of the third assignment. She did not compare uniform motion and accelerated motion with x and y components of a projectile motion. She concluded that uniform motion and projectile motion have nothing in common and tried to talk about the similarities between accelerated motion and projectile motion. The rest of this writing assignment is a summary of the projectile motion explained in the textbook. There are many conflicts between Student E's explanation of the concepts and the details presented in the textbook that she wasn't able to identify.

Student E's reflective writing Assignment 4 was clearer than the first three assignments. She explained the concepts of natural state, Newton's first law, static and dynamic equilibrium, but wasn't able to find the relationship between these concepts. The examples provided are not numerical and are related to real life experiences:

> "*Newton's first law shows that an object at rest should remain at rest unless some other unbalanced force(s) is applied to it. Another word for Newton's First Law is the idea of*

inertia. Inertia is an object's resistance to change. An example of this law is when you throw a ball up into the air. Firstly, when you just hold the ball in your hand the object is in a natural state (being at rest). When the ball is in the air a force is acted on it. There are contact forces acting on the ball; such as, the drag of the ball acting upwards. A noncontact force would be the force of gravity or the weight of the ball stopping the object from remaining a constant motion."

Student E didn't relate this assignment to uniform motion and accelerated motion concepts covered in the previous chapters.

Writing Assignments 5 and 6 are similar to Assignment 4. There are conceptual examples in addition to numerical examples to clarify the meaning of the concepts. Student E tried to make connections between Newton's second law and the concept of acceleration. There are some conflicts between the students' understanding of Newton's laws and the explanation presented in the textbook that Student E wasn't able to identify. For instance in Assignment 6, she considered normal force and weight as a pair to explain Newton's third law. She didn't realize that this example is in conflict with the explanation of Newton's third law in the textbook that clarifies you can never have a third law pair acting on the same object.

Reflective writing Assignment 7 as submitted by Student E presents a clear summary of centripetal acceleration and centripetal force in a uniform circular motion. Some concepts such as angular velocity, period, and frequency are missing. Student E used Newton's second law to explain the relationship between centripetal force and centripetal acceleration. However, she was not able to relate the other new concepts to the ones previously taught.

She provided a clear explanation of concepts in Assignment 8. Due to the examples provided in the textbook, Student E believed that an object needed to be at rest to have potential energy:

> "*An example of potential energy would be a car at the top of a hill. The car is not moving and therefore has potential energy that is stored. Potential energy is a kind of energy which is waiting for motion to happen.*"

I found that most examples related to potential energy were about objects at rest and this might have caused this misconception.

Reflective writing 9 is a summary of concepts related to momentum and collision. Even the examples provided are the same as the ones mentioned in the textbook:

> "*Impulsive force is a large force exerted during a short period of time. For example, an impulsive force could be a hammer on a nail and a bat on a baseball. The effect of an impulsive force is directly proportional to the area under a force versus time graph.*"

The explanation of concepts is clear but it is not written in the student's own words. As the student explained in the post-interview, she tried to spend more time on the writing assignment towards the end of the semester. There is a big difference between the first four assignments and the last 5 ones in terms of clarity, making connections among various concepts, and providing examples related to real life. In the post-interview she explained that labatorials helped her gain a better understanding of concepts and provided an example to support her claim:

> "*After learning the concepts in the class and doing writing assignments I still thought*

that centripetal force is the force towards the center. In the lab, first I thought that tension of the string is the centripetal force, but at the end of lab we saw that tension minus cylinder weight caused the centripetal force in the experiment. I learned about centripetal force and circular motion in the lab."

Table 6.5 shows an evaluation of Student E's reflective writing products based on the rubric provided (appendix A).

In summary, based on the pre- and post-interviews with Student E, this student displayed clear characteristics that align with a student who highly values the reflective writing activity. The explanation of the concepts in Student E's first writing assignment is unclear. Her writing assignments improved in terms of clarity by the end of the semester. By comparing her explanation of the same concepts such as acceleration and velocity at the beginning and the end of the semester, it is obvious that she experienced a horizon expansion. The last 6 assignments reveal that Student E did her best to use reasoning and explain the concepts in her own words. However, similar to other interviewees when the concepts are abstract; she copied the definition of the abstract concepts provided in the textbook. In the interviews she explained that in high school if you memorize the definition of concepts and even the ways of solving problems you will end up with a reasonable final mark, but in college you need to learn the meaning of the concepts to be able to solve the problems and answer the conceptual questions. A change in her view of learning physics from memorizing to interpretation of the concepts is obvious by comparing her first three assignments with her last six assignments.

Points Features present in the reflective writing product	RW 1	RW 2	RW 3	RW 4	RW 5	RW 6	RW 7	RW 8	RW 9
A fluent piece of work in the student's own words	1/4	1/4	1/4	4/4	4/4	4/4	1/4	4/4	1/4
Student explains all key concepts from assigned reading and lecture in his or her own words	1/4	1/4	2/4	3/4	4/4	4/4	2/4	4/4	1/4
Student relates recently introduced key concepts to previously studied concepts	0	1/4	2/4	2/4	3/4	3/4	1/4	3/4	2/4
Student relates key concepts to his/her own life experiences	2/4	2/4	2/4	4/4	4/4	4/4	2/4	4/4	2/4
Student identifies that the ideas/facts/data **(If applicable) presented in the textbook are in conflict with the students' own ideas**	2/4	2/4	0/4	2/4	3/4	1/4	2/4	2/4	3/4

Table 6.5 Evaluation of interviewee E's Reflective Writing (RW) products based on the rubric provided to the students (Appendix A)

6.6 Student F's Reflective Writing Products

In the pre-interview Student F explained that he didn't learn physics in high school and even the most basic terms such as displacement, vectors, and scalars seemed unfamiliar to him. He relied strongly on the teacher's explanation of concepts and did not enjoy writing assignments. Regarding the reflective writing assignments, he believed that writing part of the assignment didn't help him and only the reading part was beneficial. He appreciated the fact that reflective writing assignments encouraged him read the textbook. He was not able to make a connection between physics principles and his own experiences, but he found the examples provided by the course instructor very helpful. He believed that real life examples simplified the concepts.

His first writing assignment is a list of important concepts from the first chapter with a vague explanation which shows Student F did not realize the difference between displacement, distance travelled, velocity, and speed and the relationship between these concepts:

> "*Displacement is the distance travelled relative to an object's starting position. Distance is the total distance that an object travels. Speed is a scalar quantity, meaning magnitude without a specified direction, the amount of distance covered over a given amount of time, while velocity is a vector quantity, meaning magnitude and direction. Instantaneous velocity is the distance an object has travelled relative to its starting point at a specific point in time.*"

The examples provided are unclear and suggest that Student F did not gain a good understanding of the concepts covered in the first chapter. For instance the example provided to explain speed and velocity does not show the similarities and differences between these two concepts: “*If a car travels at a constant speed and moves 3m in 1 sec then its speed is 3m/s and its velocity is 3 m/s.*”

Similar to the first writing assignment, the second reflective writing piece is also unclear and the examples provided reveal the fact that the student did not understand the meaning of the concepts. For instance, the student’s explanation of acceleration shows that he thought that acceleration means an increase in velocity not change in velocity. There is a numerical example that explains a car accelerating from 0 to 8 m/s. He ignored the fact that velocity is a vector and change in velocity’s direction also results in acceleration: “*Acceleration is the change from an object’s initial velocity to a later, increased velocity over a given amount of time. The sign of the acceleration describes in which direction that object is speeding up.*” His understanding of acceleration sign is in conflict with the explanation provided in the textbook and he did not identify this conflict.

Each semester, we provide a list of the textbook sections related to each labatorial and post it on the course (Blackboard) website for students to prepare their reflective writing assignments. In Fall 2014, when we posted each writing assignment on the course (Blackboard) website we emphasized that students need to write down their own understanding of concepts and explain the materials in their own words. We also emphasized that they need to provide examples related to real life and relate the new concepts to the ones previously taught. For the third writing assignment we reminded students to relate the topic of projectile motion to uniform motion and accelerated motion. Student F did not realize that x-component of a projectile motion is uniform motion and the y-component of a projectile motion represents an accelerated motion:

“*The relationship between uniform motion and projectile motion is that they both are a* *type of motion of an object, but they differ in that uniform motion is a motion that is constant at any point throughout it's time of movement, while projectile motion changes in velocity as it is falling down towards the Earth. The relationship between accelerated motion and projectile motion is that when an object is moving in a projectile motion, the force applied by Earth's gravitational pull is a change in acceleration* [the acceleration is constant and Student F did not identify the conflict between his understanding the explanation of constant gravitational acceleration in the textbook], *therefore the object is actually being affected by the accelerated motion while it is falling in a projectile motion.*"

He did not explain the concepts of range, maximum height and time of flight in a projectile motion.

Student F's writing Assignments 4 and 5 were improved. Again, he provided a list of the concepts but each concept is explained clearly. It is great to see that in reflective writing Assignment 5, Student F realized that change in velocity direction means that velocity is not constant. When he explained the concept of acceleration in his second assignment he explained acceleration as increase in velocity's magnitude. Although there are some conflicts between Student F's explanation and the materials presented in the textbook, his writing Assignment 4 is more understandable and clearer than the first 3 assignments and the examples are well explained. His explanation shows that he gained a good understanding of Newton's first law and was able to make a connection between Newton's first law and the concepts taught previously:

"*An object that is not moving, will want to stay in that state until it is acted on by something in order to accelerate it. Conversely, if an object is moving in uniform motion* *in a certain direction, it will also want to stay in that state unless acted on by something to accelerate or decelerate it and/or change its direction.*"

In the pre-interview Student F believed that he lacked the ability to make a connection between physics principles and real life situations. In the post-interview he emphasized that it was not easy for him to think of real life examples:

"*I can't think of good examples, but when Alexis talked about real examples in the class it simplified the complicated concepts. I know that thinking about the application of theories in life helps a lot but I honestly can't provide good examples. But I became better by the end of semester.*"

By comparing Student F's writing assignments it is obvious that his writing products improved during the semester in terms of clarity and providing real life examples.

In writing Assignment 6, after explaining the listed important concepts, he provided an example to clarify Newton's second law. It is great to see that he started integrating figures and diagrams in his writing assignment:

"*If a cake is sitting, motionless on a horizontal surface the free body diagram would show two arrows of equal magnitude, one for the force of gravity (in the downwards direction) and one for the normal force (in the upwards direction). Because this cake is motionless, it is not being pushed so there is no applied force nor is there a force of friction. There are only two forces acting on it (gravity and normal), which correspond to the arrows of the cake's free body diagram. These arrows would be of equal magnitude because the cake is not accelerating in either the up or down direction, the forces equal and cancel out, displaying a net force of zero. But if I apply a force on the cake to slide it on the* *table and the applied force is bigger than friction then object starts moving from zero and so it has acceleration.*"

As Student F explained in both pre- and post-interview, the examples provided in the class and textbook helped him come up with examples. The example of the cake is similar to the example of pushing a box in the textbook.

Student F explained Newton's third law briefly in his writing Assignment 6. There is no conflict between the student's explanation of Newton's third law and the explanation presented in the textbook. Based on Student F's writing products, I believe that he gained a good understanding of Newton's laws and their applications.

I found Student F's writing product about circular motion vague and confusing. It is obvious that he did not understand the concept of uniform circular motion and so was not able to make a relationship between this topic and the materials taught previously in the course. He provided a vague explanation of centripetal acceleration and force and was not able to use Newton's second law to make a connection between these two concepts:

> "*Centripetal acceleration is an object moving with uniform acceleration in circular direction. Centripetal force is a center seeking force and is a motion in a curved path that represents accelerated motion and requires a force.*"

Student F provided a summary of the definition of the main concepts to explain the relationship between heat, work, and energy in writing Assignment 8. However, he explained his own understanding of these concepts by providing real life examples. He realized that there are mechanical and non-mechanical ways to change the energy of a system and tried to relate this topic to other physics concepts.

I found the last writing assignment provided by Student F unclear and confusing. I believe that when he had trouble understanding the meaning of concepts the language used to explain them was vague and confusing. He provided a good explanation of Newton's laws, but his explanation of circular motion in Assignment 7 and momentum in Assignment 9 are confusing. The terms used to explain the meaning of centripetal force and momentum are not appropriate. For instance he used the term "motion" inappropriately to explain centripetal force: "*Centripetal force … is a motion in a curved path*" and used the term "motion" to explain momentum: "*Momentum is a motion with velocity and mass*". Even if Student F had difficulties providing real life examples and making relationships among various physics concepts, his writing products improved during the semester and in general his last seven assignments are clearer and more understandable than the first three. Table 6.6 shows an evaluation of Student F's reflective writing products based on the rubric provided (appendix A).

Student F was the only interviewee who did not enjoy reflective writing activities. He believed that writing part of the assignment didn't help him and only the reading part was beneficial. His reflective writing assignments confirm his statement. He gained the lowest mark among all interviewees. He was not able to make a connection between physics principles and his own experiences in the first assignments, but there are real life examples in his last assignments.

Points Features present in the reflective writing product	RW 1	RW 2	RW 3	RW 4	RW 5	RW 6	RW 7	RW 8	RW 9
A fluent piece of work in the student's own words	1/4	1/4	1/4	2/4	3/4	4/5	0/4	3/5	1/4
Student explains all key concepts from assigned reading and lecture in his or her own words	1/4	1/4	1/4	2/4	2/4	4/5	1/4	4/5	1/4
Student relates recently introduced key concepts to previously studied concepts	0	0/4	1/4	3/4	3/4	3/5	0/4	5/5	1/4
Student relates key concepts to his/her own life experiences	1/4	1/4	1/4	3/4	3/4	4/5	1/4	4/5	1/4
Student identifies that the ideas/facts/data (If applicable) presented in the textbook are in conflict with the students' own ideas	0/4	0/4	0/4	3/4	3/4	N/A	2/4	N/A	1/4

Table 6.6 Evaluation of interviewee F's Reflective Writing (RW) products based on the rubric provided to the students (Appendix A)

6.7 Student G's Reflective Writing Products

At the beginning of the semester I always post a sample of a reflective writing assignment on the Blackboard. In winter 2015, I used Student G's first writing assignment as a great example of reflective writing. When I asked Student G about her way of doing reflective writing in the pre-interview she explain that she first reviewed her class notes and then read the book. After reading each section she wrote a summary of the main concepts and then moved to the next section. She followed the same strategy to cover all sections and then tried to find the relationship among all these sections. She thought about the application of the main concepts in each section and tried to come up with an example that engaged all these concepts and the relationship between them. She reviewed the summary of each section and then started writing about what she had summarized in her own words. In the post-interview she explained that she followed the same strategy during the whole semester and believed that it worked well. Student G's first assignment is a story about her running experience at the "Color Me Rad 5K" event in summer that includes the explanation of displacement, distance, velocity, and speed in her own words. For instance she clarified the relationship between velocity and displacement and the difference between speed and velocity:

> "*If someone were to ask for my speed during the race, I may say 2m/s since I'm not really a fast runner. However, if they asked for my average velocity then I would say 0m/s. The reason being is because speed is how much distance was covered over a specific time. Velocity on the other hand is connected with displacement. If my displacement is 0, then it doesn't matter what my speed is, because the average velocity will be 0m/s.*"

She explained the relationship between speed and average velocity and finished her first assignment with a question:

> “*In a uniform motion the magnitude of average velocity is the same as speed since displacement and distance travelled are the same in a uniform motion. After reading this chapter and thinking about the concepts I guess the magnitude of instantaneous velocity in both uniform and accelerated motion is the same as speed. Am I right?*”

It is great to see that Student G explained all concepts in her own words and thought about the relationship among them and came up with questions.

In the second writing assignment, Student G provided a detailed explanation of the main concepts in her own words. She presented her own way of explaining the sign of acceleration in a one dimensional accelerated motion:

> “*I have my own explanation of acceleration sign. Let’s show speeding up with a positive sign and slowing down with a negative sign. When an object is moving towards the positive direction of an axis then the direction of motion is positive and if an object is moving towards the negative direction of an axis then the direction of motion is negative. We know that a negative times a negative equal a positive. So an object slowing down towards the negative direction has a positive acceleration. A positive times a negative equal a negative and so an object speeding up towards the negative direction or an object slowing down towards the positive direction has a negative acceleration. A positive times a positive equal a positive and so an object speeding up in the positive direction has a positive acceleration.*”

Assignment 3 about projectile motion contains one paragraph. It is a summary of the motion along x- and y-components of a projectile. Student G explained the reason why she did not provide any examples:

> "*When I play volleyball the only force acting on the ball is not gravitational force. Air resistance influences the trajectory and all variables related to the projectile motion such as maximum height and range. Therefore, I cannot provide any example to explain a projectile motion.*"

Student G has provided her own explanation of natural state, Newton's first law, static equilibrium, and dynamic equilibrium in reflective writing Assignment 4 and then concluded that all these concepts explain the same situation in which net force is zero and there is not acceleration:

> "*I believe natural state, Newton's first law, static and dynamic equilibrium all explain the same thing. They all are about the situation in which the net force is zero and acceleration is zero. Dynamic equilibrium is about uniform motion and static equilibrium is when the body is at rest and the net force is zero.*"

Student G related these concepts to uniform motion that was covered in Assignment 2.

Student G explained both Newton's second law and Newton's third law in one assignment and provided examples to explain the relationship between them:

> "*I use Newton's third law and Newton's second law when I go swimming with my friends and we try to race each other. While starting I use my feet to push off the wall. The more force I apply on the wall, the faster I am moving in the water. This is because the wall exerts the same force on me as I apply on the wall, but in the opposite direction. When the force from wall on me is bigger, based on Newton's second I have a bigger*

acceleration which means that change in velocity in a time interval is bigger and I have a great chance to win the race."

Student G also related Newton's first law and Newton's second law and also integrated diagrams and photos in this assignment:

"*An object in motion at constant velocity will continue to remain in motion in a straight line unless an outside/unbalanced force acts on it. It is this outside/unbalanced force known as net force that when acting on an object can change the velocity (magnitude and/or direction) and cause the object to accelerate that creates Newton's Second Law. It is simply a continuation of Newton's First Law. After reading the textbook section on Newton's second law, the figures and examples seemed confusing to me. I had no idea why forces acting on an object were projected on x and y axis. But when I understood the relationship between outside/unbalanced force and acceleration they all made sense.*"

Student G described uniform circular motion in her own words and related this topic to Newton's second law in Assignment 7: "*In the last assignment we discussed that an outside/unbalanced force can change the velocity and create acceleration. An outside unbalanced force changes the direction of velocity in a uniform circular motion and creates centripetal acceleration.*" There are many equations presented in the textbook to explain circular motion and orbits. Student G explained the concepts of centripetal force and centripetal acceleration in this assignment and missed explaining many concepts such as angular velocity, frequency, and angular position.

Student G started integrating equations and diagrams in her writing assignment from Assignment 5 about Newton's second law. In Assignments 8 and 9 she interpreted the equations with the help of figures provided in the textbook:

> "*Impulsive force is a large force exerted during a short period of time. For example, an impulsive force could be a hammer on a nail and a bat on a baseball. The effect of an impulsive force is directly proportional to the area under a force versus time graph. This area is calculated and known as the impulse of the force. This seemed confusing to me at first but then I looked at a graph in the book showing the force of the floor on a bouncing ball and this made the relationship between impulse and average force understandable. To find the area under the force curve I needed to find the area under a triangle, which is the time interval multiplied by the height (max force in this example) divided by 2. The average force is equal to the half of the maximum force and this confirms the fact that impulse and average force have the same direction.*"

Student G explained the concepts of work and energy in her own words in Assignment 8 and tried to relate these concepts to the materials taught previously. Assignment 9 has the style of both reflective writing and summary writing. The explanation of abstract concepts such as momentum is a summary of what was presented in the book without the student's interpretation. However, the concepts of elastic and inelastic collisions that we see around us in real life are explained in the student's own words. Table 6.7 shows an evaluation of Student G's writing products based on the rubric provided (appendix A).

In summary, based on the pre- and post-interviews with Student G, this student displayed clear characteristics that align with a student who highly values the reflective writing exercise, and as such clearly developed his reflective writing skills over the course of the term, while simultaneously improving his physics understanding. These conclusions are supported by Student G's statements in the pre- and post-interview and his reflective writing products. Reflective writing assignments provided by Student G confirm that she used reasoning to explain the principles and find the relationship among various physics concepts. Her statements in the interviews are consistent with what she did during the semester. In the post-interview Student G emphasized that her pre-understanding expanded during the semester and lots of activities including reflective writing assignments helped her shape her present ideas. A general improvement in her explanation of the concepts confirms that her horizon expanded during the semester. Similar to other interviewees, the explanation of abstract concepts in Student G's writing assignments is a summary of what was presented in the book.

	Points Features present in the reflective writing product	RW 1	RW 2	RW 3	RW 4	RW 5	RW 6	RW 7	RW 8	RW 9
1	A fluent piece of work in the student's own words	5/5	5/5	4/5	5/5	5/5	5/5	5/5	5/5	3/5
2	Student explains all key concepts from assigned reading and lecture in his or her own words	5/5	5/5	3/5	5/5	5/5	5/5	2/5	5/5	3/5
3	Student relates recently introduced key concepts to previously studied concepts	5/5	5/5	4/5	5/5	5/5	5/5	3/5	5/5	5/5
4	Student relates key concepts to his/her own life experiences	5/5	5/5	2/5	5/5	5/5	5/5	4/5	5/5	4/5
5	Student identifies that the ideas/facts/data (If applicable) presented in the textbook are in conflict with the students' own ideas	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 6.7 Evaluation of interviewee G's Reflective Writing (RW) products based on the rubric provided to the students (Appendix A)

6.8 General Analysis of Interviewees' Writing Products

The evaluation of interviewees' reflective writing products shows that after doing the first three reflective writing assignments, students' writing became clearer. Students also showed improvement in integrating diagrams and explaining the meanings behind the equations presented in the textbook. In the first writing assignment students were not familiar with the reflective writing activity and most interviewees did not get a good mark for the writing assignment. Looking at the rest of the assignments, I found that the quality of writing was heavily dependent on how well the students understood the content. When the topics contained a lot of equations and formulas or the concepts were more abstract, students' writing was not as clear, understandable, or well organized and correspondingly the writing products were not usually in the reflective writing style. For instance the third writing assignment about projectile motion, writing Assignment 7 about uniform circular motion and the last assignment about momentum and conservation of momentum in elastic and inelastic collisions were in the summary writing style. Table 6.8 identifies the assignments that had a reflective writing (RW) style as opposed to the ones that presented a summary of the assigned textbook sections. As can be seen in Table 6.8, the assignments with a summary writing style tended to be the ones about projectile motion, circular motion, and the assignment about momentum and conservation of momentum.

To examine the consistency of results gained I evaluated the writing products of 41 students who completed reflective writing assignments in fall 2014 and gave me permission to use their writing products in this study. Figure 6.1 shows a bar graph of assignments of 41 students that were in the style of reflective writing, summary writing or was a combination of reflective writing and summary writing.

Interviewee	RW1 – Uniform Motion	RW2 – Accelerated Motion	RW3 – Projectile Motion	RW4 – Newton's First Law	RW5 – Newton's Second Law	RW6 – Newton's Third Law	RW7 – Circular Motion	RW8 – Energy and Work	RW9 – Collision and Momentum
Student A	Summary Writing	Reflective Writing	Reflective Writing / Summary Writing	Reflective Writing	Reflective Writing	Reflective Writing	Summary Writing	Reflective Writing	Summary Writing
Student B	Reflective Writing / Summary Writing	Reflective Writing	Reflective Writing	Reflective Writing	Reflective Writing	Reflective Writing	Reflective Writing	Reflective Writing / Summary Writing	
Student C	Reflective Writing / Summary Writing	Reflective Writing	Reflective Writing / Summary Writing	Summary Writing	Reflective Writing	Reflective Writing	Summary Writing	Reflective Writing	
Student D	Reflective Writing / Summary Writing	Reflective Writing / Summary Writing	Summary Writing	Reflective Writing	Reflective Writing	Reflective Writing	Reflective Writing / Summary Writing	Reflective Writing / Summary Writing	
Student E	Reflective Writing / Summary Writing	Reflective Writing / Summary Writing	Reflective Writing / Summary Writing	Reflective Writing	Reflective Writing	Reflective Writing	Summary Writing	Reflective Writing	Summary Writing
Student F	Summary Writing	Summary Writing	Summary Writing	Reflective Writing / Summary Writing	Reflective Writing / Summary Writing	Reflective Writing / Summary Writing	Summary Writing	Reflective Writing / Summary Writing	Summary Writing
Student G	Reflective Writing	Reflective Writing	Summary Writing	Reflective Writing	Reflective Writing	Reflective Writing	Reflective Writing	Reflective Writing	Reflective Writing / Summary Writing

Style of Writing:
- **Reflective Writing**
- **Summary Writing**

Table 6.8 Style of writing used by interviewees

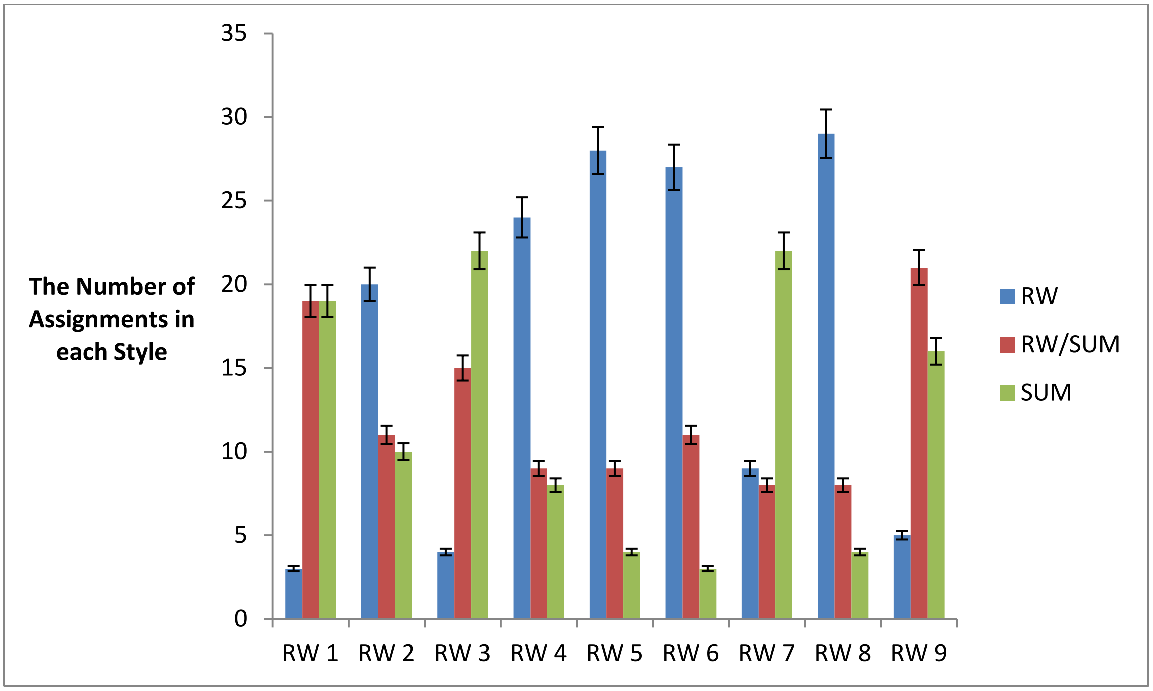


Figure 6.1: A bar graph of writing assignments' styles of 41 students: Reflective Writing (RW), Summary Writing (SUM) or a combination of Reflective Writing and Summary Writing (RW/SUM)

Figure 6.1 is consistent with Table 6.8 that shows the style of writing assignments completed by interviewees. Figure 6.2 shows the students' reflective writing grades during the semester. Assignments 1, 3, 7, and 9 have the maximum numbers of writing assignments with summary writing style. Reflective writing is worth 20% of the lab mark which is 2 out of 10.

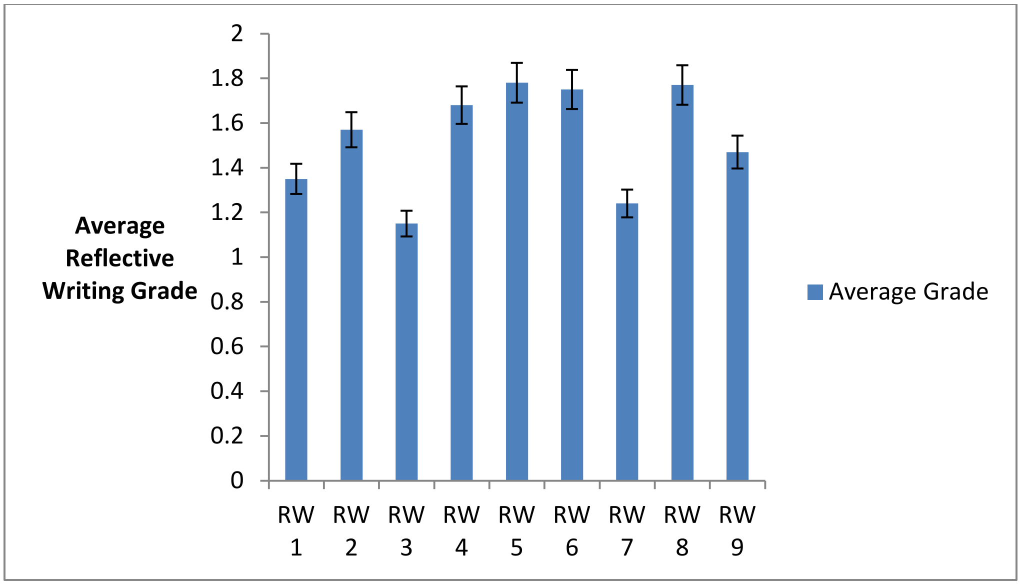


Figure 6.2: The average Reflective Writing (RW) grade of 41 students who completed reflective writing assignments in fall 2014

As you see in Figure 6.2, I believe that the low average mark of the first assignment is due to the fact that students were not familiar with reflective writing and most assignments were in summary writing style and there were no real examples to clarify the meaning of concepts. The feedback on the first assignment helped students improve their second writing activity. As you see in the bar graph the third assignment about projectile motion has the lowest average grade and Assignment 7 about circular motion has the second lowest average mark. I believe that it was easier for students to visualize motion and force in one dimension. All examples provided by students to explain acceleration and Newton’s second law are in one dimension. In the topic of projectile motion and circular motion students need to think about motion in two dimensions and the effect of forces in a two dimensional case which violates their intuition that things always go in the direction that one kicks them (White, 1984). There is a decrease in the average writing activity grade from Assignment 8 to Assignment 9. Writing assignment 9 was about momentum and conservation of momentum in elastic and inelastic collisions. Most students copied the definition of momentum from the textbook and were not able to explain the concepts of momentum and impulse in their own words. I believe that when writing assignments were about concepts that are abstract such as momentum, there were fewer writing products with a reflective writing style since students are not familiar with such concepts and it is not easy for them to relate abstract concepts to their real life experiences. I added the writing assignment marks of the seven interviewees to the 41 students analyzed in fall 2014 and found the average grade of each assignment. Figure 6.3 shows the average grade of 48 students who completed reflective writing assignments.

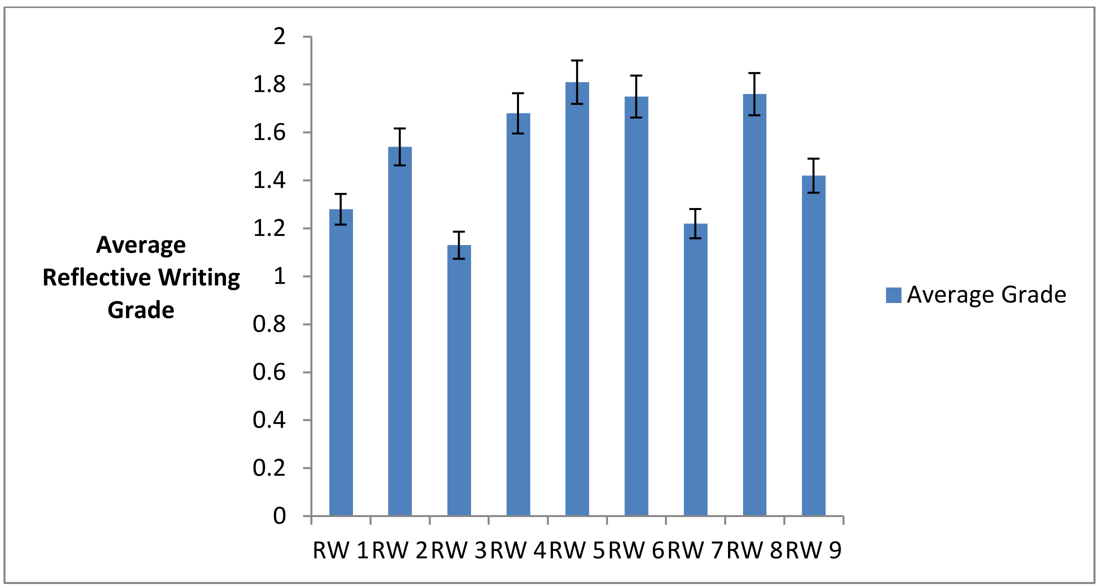


Figure 6.3: The average Reflective Writing (RW) grade of 48 students including interviewees who completed reflective writing assignments in fall 2014

By comparing Figures 6.2 and 6.3 we see that the trend of change in writing assignment marks is the same. Based on the analysis of interviewees' reflective writing assignments and 41 students' reflective writing products we can conclude that:

- Students' reflective writing assignments became clearer and more understandable by the end of semester.
- There is an improvement in integrating diagrams and figures in writing assignments to clarify the meaning of concepts.
- There is an improvement in integrating equations and explaining the concepts behind the formulas presented in the textbook.
- The quality of writing is heavily dependent on the topic
- The style of writing depends on how well the students understand the content.

I analyzed each interviewee's reflective writing product in this chapter and provided some examples to clarify my interpretation. I provided some examples from the reflective writing assignments of 41 students that I evaluated in fall 2014 to explain the conclusion (Tables 6.9 and 6.10). Tables 6.9 and 6.10 show some examples of the way students explained the same concepts at the beginning and end of the semester.

Student	Explanation of a concept at the beginning of the semester	Explanation of the same concept at the end of semester
1	The concept of acceleration is the amount of how fast an object is moving by time.	An unbalanced force can change the direction or magnitude of velocity. We know that acceleration is related to change in velocity and so there is a net force acting on an object in an accelerated motion.
2	Displacement is the area travelled by an object with respect to a starting point and the distance is the whole area travelled from the starting point to the final point.	The work done by a force is related to the displacement. Displacement is a vector that shows the position of an object with respect to its initial position.
3	A projectile motion is a uniform motion since the initial velocity is the same as final velocity and velocity is zero in the middle and the parabola is uniform. The acceleration is also uniform and is -9.81.	Dynamic equilibrium is the same concept as uniform motion in which velocity is constant and acceleration is zero.
4	Velocity is a vector quantity, meaning magnitude and direction which is the distance an object has travelled relative to its starting point at two specific points in time.	In a dynamic equilibrium, velocity is constant which means that change in object's position over a given amount of time is constant.
5	Acceleration means speed is increasing and deceleration means speed is decreasing and accelerated motion means uniform increase in speed and has a direction since it is a vector.	An object accelerates when its velocity changes. Newton's second law shows that when an unbalanced force acts upon on an object the velocity changes and object accelerates.
6	Acceleration is the slope of velocity and velocity has a slope when object moves uniformly and this means that acceleration is constant and slope of acceleration is zero. A positive slope of velocity means that acceleration is positive and doesn't mean that direction of motion is positive even if it is positive.	Acceleration and velocity have the same sign when an object is speeding up. An object speeds up when I drop it and so acceleration must be negative since velocity is downward. When it comes to Newton's second law, net force is downward and has the same direction as acceleration.

Table 6.9 Students' explanations of the same concepts at the beginning and end of the semester

Student	Explanation of a concept at the beginning of the semester	Explanation of the same concept at the end of semester
7	Acceleration is most closely related to position versus time, just has a magnitude since it is a vector.	Acceleration is a vector quantity meaning it has direction and magnitude. Acceleration is the rate of change of an object's velocity in relation to the time. Newton's second law states that an object's acceleration is dependent on two variables, the net force acting on it, and the object's mass.
8	Acceleration is the curve of velocity time graph. In a velocity time graph the line would curve representing that the object is speeding up. In a uniform motion velocity time graph is a straight line. An example of acceleration would be a car speeding up from rest after the traffic light turns green. In this example acceleration is positive. Acceleration can also be negative which shows that the object is slowing down.	Newton's second law of motion states that when a net force acts on an object, it will change the object's velocity and cause an object to accelerate. The shape of the velocity time graph reveals useful information about the acceleration. A horizontal line shows that acceleration is zero. A positive slope shows a positive acceleration and a negative slope shows a negative acceleration.
9	Uniform motion is a constant velocity time period, which means you were traveling at a steady unchanging speed at any time.	Uniform motion is when an object is travelling at a constant velocity. When velocity is constant then acceleration is zero. If a body has no acceleration, then the forces acting on it must be in equilibrium and so there must be a zero net force.
10	Displacement is the change in position while distance is the total displacement travelled.	By reading the textbook I learned that gravitational potential energy depends on the height of an object not the path travelled. I conclude that gravitational potential energy depends on the displacement in y direction. Now I understand the distinction between distance and displacement. Displacement is the difference in where you start vs where you end, while distance is the total path covered.
11	Uniform motion is a pretty easy one to explain, in that it is the movement an objects makes in constant time without changing the position in each period of constant time and how fast it is going.	Newton's first law states that every object stays at rest or in uniform motion (motion in a straight line with constant speed and direction) unless a net external force acts on it.
12	Uniform motion is the rate at which an object moves at equal distances. It doesn't mean that direction of motion is positive even if it is positive. A pendulum would be going in uniform motion because it is travelling the same distance every time.	The key point is that if there is no net external force acting on an object and thus the object maintains a constant velocity. If that velocity is zero, then the object stays at rest. If the velocity is not zero, then the object maintains that velocity and moves in a straight line, which means the direction of motion is also constant.

Table 6.10 Students' explanations of the same concepts at the beginning and end of the semester

By looking at students' reflective writing products, I found that more students started integrating equations and explaining the concepts behind them after doing the first 5 writing assignments. One example of interpreting kinetic and potential energy equations is provided here:

> "*Kinetic Energy describes an object's energy during motion. This makes sense when you look at the kinetic energy formula (Kinetic Energy is calculated by multiplying mass of the object moving to its speed squared divided by two). It means that an object must be moving with speed v to have kinetic energy. Potential energy is a kind of energy that can be stored in an object and has the potential to be changed to another type of energy. The gravitational potential energy in an apple lifted up the earth with respect to the ground is calculated by mgh equation, while the spring potential energy is calculated by multiplying the spring constant to the object's displacement squared divided by two. I conclude that potential energy is related to the position. In the case of gravitational potential energy the elevation is important, while in the case of spring the displacement of the end of the spring matters.*"

Table 6.11 shows some examples of students' interpretation of diagrams and figures.

In general the quality of writing assignments and the writing assignments grades are heavily dependent on the topic. As you see in Figures 6.1 and 6.2, the average grades of assignments 2, 4, 5, 6, and 8 are higher than the other assignments. Assignments 3, 7, and 9 have the lowest average marks of all. The style of writing also depends on the topic and how well the students understand the content. If they understood the concept the writing assignments were in a reflective writing style and if they didn't understand the topic well, the writing assignments were in a summary writing style.

Student	Interpretation of figures and Diagrams
1	When I started reading Section 5.2 I got so confused. I had no idea how to use the acceleration to find out the final position. I realized that I didn't understand the second chapter. I reread Sections 2.2 and 2.4 and compared and analyzed the graphs provided in Figure 2.31 to find out the difference between uniform motion and accelerated motion. Figure 2.31 also helped me make sense of the equations in section 2.5.
2	I had no idea how to solve the assignment questions related to centripetal force. I was looking for a general equation to find centripetal force in different situations. I also used Newton's second to isolate centripetal force. When I read the textbook to complete my lab assignment I found that centripetal force is never included in Newton's laws. Figure 6.21 helped me understand the concept of centripetal force. Centripetal force is labeled as the net force in Figure 6.21. Normal force and weight result in a net force towards the center in Figure 6.21.
3	The law of conservation of momentum means that the total momentum after an interaction is equal to the total momentum before an interaction. It means that the velocity of an object must stay the same after an interaction. Figure 7.9 shows that there is a force acting on the object striking a wall and so the final velocity is not equal to the initial velocity. Figure 7.9 helped me realize that conservation of momentum is related to the net force acting on an object.
4	The relationship of work and heat to energy transformation seems confusing at first. Figure 8.1 shows that how the angle between force and displacement can change the sign of work done and how the sign of work represents energy transformation.
5	I thought that normal force is always upward and against gravity. After reading Section 4.3 I found that normal force is not a force against gravity, but a force exerted by a surface against an object pushing that surface. Figures 4.10 shows an example of normal force in the –x direction as a result of pushing a wall and 4.11 shows the normal force that an inclined plane exerts on a skier.
6	It wasn't easy for me to understand the concept of apparent weight. I read Section 5.3 several times and wasn't able to make sense of equation 5.9 which relates the apparent weight to a_y and g. However Figure 5.12 helped me understand the concept of apparent weight. Since the man in the elevator is moving upward and the acceleration is upward then there must be a net force upward. The net force is the difference between the spring force and the man's weight.

Table 6.11 Students' interpretation of diagrams and figures

Chapter 7: The Key Aspects that Make Reflective Writing Successful at Achieving Effective Student Learning Outcomes

As discussed in the first chapter, the majority of publications in the field of writing-to-learn (Mullin, 1989; Hein 1999; Larkin, 2000; Larkin & Budny, 2001; Joyner & Larkin, 2002; Kirkpatrick and Pittendrigh, 1984; Hermsen & Franklin, 2006) introduced a writing activity and discuss the benefits based on comments left by students and the instructors' observation. There are two major problems associated with this type of publication. First, we do not truly know if those writing activities were successful at effectively achieving desired learning outcomes since there is usually no incontrovertible qualitative or quantitative evidence for the concluding claims made. Second, if they really were helpful, we do not know the reasons or what specific characteristics of the activity made it successful. In this chapter we will discuss the students' perspectives on reflective writing and the main aspects that make reflective writing a successful activity. To extract clear and effective information on this matter, this work will focus on the qualitative data generated in the interviews with all seven students who participated in this exercise associated with Physics 1201 at MRU, as it is the interview data that allows us to probe the depths of the students' understanding and motivations.

7.1 Student A

In the pre-interview, Student A mentioned that reflective writing assignments involved thinking. Even if he didn't like this activity at the beginning of the semester, he believed that there is a lot of value in doing such writing assignments:

> "*when I read the textbook to do reflective writing I try to connect it to what I know from before and what I see in real life. I tried to connect free fall to my experience of*

skydiving. I try to compare what I know with what I see in the textbook. Because we need to explain the concepts in our own words we have to make sure what we get does not contradict what is written in the textbook."

Student A had found some parts in the textbook not covered in the class and found the details helpful in problem solving. He believed that understanding is required to solve the problems:

"*Physics is not memorizing. You need to understand physics to be able solve the problems. They give us a formula sheet at each exam, but many students do not know how to use them. Because we need to understand the concepts to be able know which equation is the right one to use. Reflective writing makes you think. By providing examples, it makes a connection between physics and life.*"

During the post-interview he argued that reflective writing helped him think about the concepts and made him read the textbook and this helped him in problem solving. He believed that reflective writing values students' perspectives and pre-understanding. It helped him come up with good questions and made him feel confident to express his ideas:

"*Reflexive [sic] writing made asking questions easy. When I am not ready before a lecture or lab I find my questions stupid and sometimes I am not brave enough to ask them. But after doing reflective writing, you have done your best to make sense of the materials and you actually come up with great questions and you are not scared to ask them in the lab or class. It makes you confident to express your ideas and ask questions. Reflexive [sic] writing familiarized me with the concepts prior to the lab. It also helped* *me answer the conceptual questions in the worksheet and understand the experiments better*."

Reflective writing helped him answer the labatorial worksheet questions and improved his performance in the lab. He argued that explaining is a key to understanding and reflective writing involves explaining the concepts and this helped him understand the physics concepts in this course:

"*Reflexive [sic] writing makes you think about what you read. As I said it is like you are explaining what you read and if you understand it then you can explain it. It makes you read the textbook. You actually read ahead and so you are ready when you go to the class and lab. Labs also helped me a lot. They made me think about the concepts. There are lots of questions about the concepts before doing the experiment. You actually see the application of concepts and equations and this makes you understand the lectures better. I never thought about the concepts while solving a problem but I learned that by knowing the concepts you can solve the problems better. Reflexive [sic] writing made me more curious about the things that happen around me. To provide an example related to each concept I tried to look around and this made the course more interesting.*"

As discussed previously, reflective writing helped Student A change his ideas about learning physics during the semester. At the beginning of the semester he tried to solve the problems and worked on the assignments without knowing the concepts behind the topic. By the end of the course he appeared to be trying to understand all concepts well before getting involved in solving problems. Reflective writing made him read the textbook, and it provided him with motivation not just to read the material, but to try to understand it:

"At the beginning of the semester I just wanted to solve the problems and to save time I only studied the lecture notes. When I started reading the textbook to do writing assignments, I found many details and explanations that were not covered in the class and lecture notes and this made me understand the material better. In my opinion I understand something when I can teach it or explain it. Reflexive [sic] writing is like explaining materials. By understanding the concepts better of course you can solve the problems better."

Through reflective writing he learned the reasons behind the concepts he memorized in high school and so dealing with problems became easier for him. Student A's statements are consistent with his writing assignments. In general his writing products became better during the semester. As described previously, in most of his writing a summary of the key concepts presented in the textbook was followed by his own understanding of them.

7.2 Student B

During the pre-interview, we found that Student B was not a fan of writing but he considered reflective writing as a helpful activity that made him read the textbook. He believed that it is crucial to know the principles in order to understand and solve the problems and reflective writing made him read the textbook and gain a good understanding of concepts:

"Physics is a problem-solving course so I read my notes and the sections of the textbook explaining the main principles stressed in the class. I need to know the principles to be able to understand and solve the problems. I think reflective writing is a helpful activity. I'm not a fan of writing in general, but it is better than writing a lab report. I gain nothing by writing a lab report but this activity makes me read the textbook and make

sense of the concepts so it's helpful."

He also found it helpful to have a summary of principles when he is not able to read the whole textbook for the exams. In addition, reflective writing kept him on track:

> "*It's helpful to have a summary of the textbook principles. I may not be able to read the whole textbook or the final exam and so I can review my writing assignments. This writing activity keeps me on track. I have to read the textbook and this helps me follow the class. It's helpful for solving the problems. You need to know the principles to understand and solve a problem.*"

During the post-interview Student B mentioned that he learned the reasoning and meaning behind what he had memorized in high school and this improved his problem solving skills during the semester. He considered reflective writing as an activity that encouraged him to use his pre-understanding:

> "*When I find the application of a theoretical concept in life I understand it better. When I perform the experiments and the results support the theory then I understand the theory better. When I see a new concept that I have no idea about I become nervous but when I have even a basic background about a subject then I am relaxed and I get a better understanding. It happens when I'm not prepared when I go to the class and sometimes I get lost, but when I read before going to the class then I understand the concepts better. This is why I like the lab writing assignments since I had to be prepared before doing the experiments and they helped me think about what I already knew and experienced.*"

By explaining the concepts in his own words Student B obtained a good understanding of physics concepts in this course. He came up with many questions and this increased his interaction with the lecture professor and also made the course enjoyable:

> "*Reflective writing made me read the textbook carefully. We were supposed to explain the concepts and make sense of them and this, this strategy made me understand the physics concepts. Without reflective writing I wouldn't read all section. It helped me come up with many questions and I had a good interaction with the lecture professor and I actually enjoyed this course.*"

He emphasized that reflective writing is an activity that involves thinking. Regarding the role of reflective writing in the lab, he argued that he was prepared before doing each experiment and this helped him follow the class.

7.3 Student C

In the pre-interview Student C mentioned that she was not a fan of writing, but the reflective writing activity made her read the textbook after each lecture and so she thought it would be a helpful activity:

> "*I read the textbook to be able to solve the problems. I'm not a fan of writing, but it makes me read the textbook after each lecture and that's good. It's good to be prepared before doing an experiment. Experiments in Physics 1201 are related to the lectures and it's good to read the theory before doing the experiment.*"

Another reason why she valued this activity was because she was prepared before doing each experiment. In addition, reflective writing improved her engagement:

> "*When I review the previous lecture before going to the class I learn the new materials better. Reflective writing makes me read the text. I get a better understanding of the*

principles covered in the classroom. It's always great to study the material presented in the class. If not, you'll be overwhelmed with lots of new concepts and it's almost impossible to learn them all at the same time."

In the post-interview she emphasized that she had to write about the main principles and so she had to think about what she knew about them already. This shows that reflective writing made her approach the text in the manner of hermeneutics: "[reflective writing] *helped me think about the principles. I had to explain the principles and provide some examples. So it made me examine my experiences and what I learned so far.*" Student C's first four writing assignments are very different from the rest. Her writing assignments confirm that she actually started making sense of the concepts after the first midterm. She explained that:

"*I'm less worried when I see a familiar principle, because I know it already. Then I am prepared to learn more about it. But when all the principles presented is new [sic] then I get worried because I can't learn lots of new things all together and then after learning two or three my mind stops working.*"

7.4 Student D

Student D found reflective writing helpful since it made him read the textbook and he learned about many details not covered in the class. In the pre-interview he explained that thinking about real life situations related to the main concepts made him enjoy the course. He needed to understand the concepts in order to answer the questions and solve the problems in physics:

"*I usually prepare a summary of what I read. I understand the material better when I write. Especially when you study physics and math you need to have a pen and paper to* *draw pictures, write a summary of concepts and so on. Because you need to understand physics. It's not memorizing. When you understand the terms then you can use them to answer the questions and solve the problems.*"

Reflective writing helped him read the textbook effectively before each lab and so he got a better understanding of what was going to be covered in the lab. It made him see the world through the lens of physics and this made complicated concepts sensible and easy to understand for him:

"*It's helpful to find the main principles and see what textbook says about them. It's helpful to compare the class notes with what you read. Reflective writing helps me read the textbook before each lab and so I get a better understanding of what we are going to do in the lab. As I said before it makes you see the world through the lens of physics and this makes complicated concepts sensible and easy to understand.*"

In the post-interview he emphasized that reflective writing helped him think about the relationships among various concepts:

"*Reflective writing made me read the book and make sense of what I read. It helped me think about the relationship between various concepts. It helped me think about the application of physics principles in real world. Thinking about the various concepts in real life and the way they are combined to explain a phenomenon helped me understand the connection between them.*"

He appreciated the evaluating criteria that encouraged him to express what he really gained after reading each section of the textbook. He felt free to explain his own understanding of concepts without being worried about marking. He explained reflective writing as an activity that is not just writing down something, but an activity that involves logic, thinking and patience:

> "*I like the way the writing assignments were evaluated. I wasn't worried about being judged for writing my own understanding of principles. Doing reflective writing took a long time but I learned a lot and I found it so helpful. It's not just writing down something, it involves logic, thinking and patience.*"

As the course progressed he spent more time doing reflective writing since he needed to think about the relationships between the new concepts and the concepts covered in previously:

> "*As* [I] *moved forward it took more time* [to prepare the writing assignments] *since I had to think about the previous chapters to relate the principles. Writing involves a level of thinking. The labatorial writing assignment needed a high level of thinking since we needed to write down what we understood by reading the assigned sections. Because of reflective writing I read the textbook carefully and learned many things not covered in the classroom due to the time restriction. Sometimes you think that you have understood a concept but when you want to write about it you have no idea what to write. I think you get a great understanding of a concept when you can explain it to someone or write it down. For me, writing is like explaining something.*"

Student D believed that coming up with an explanation can help students learn more effectively than having an explanation handed to them and reflective writing provided an opportunity to explain the concepts in their own words.

7.5 Student E

Student E also did not like reflective writing activity at the beginning of the semester. In the pre-interview she explained that preparing the first writing assignment took a long time and the weight of the reflective writing grade is not consistent with time she spent to prepare her first assignment. However, she believed that reflective writing activity was helpful since it encouraged her to read the book and explain the concepts:

> "*I don't like them* [writing assignments]. *Too much work. It's good that we don't have to write a lab report and instead we write about the concepts. But you know I am not a fan of writing in general. They* [writing assignments] *make you read the book and explain the concepts. I know that they are helpful but I am so busy this semester. I prepared the first writing assignment and it took a long time. What I don't like is how through the reflective writing assignments must be when comparing the weight of the grade to the length of written work... If I had three or four courses this semester then I had more time to spend on writing assignments and I would enjoy writing about physics.*"

Student E emphasized that mathematics and physics are problem solving disciplines and it is crucial to learn the concepts to be able to solve the problems. She explained that reading the book helped her gain a better understanding of materials and improved her problem solving skills:

> "*I believe solving problems is the most important thing in physics and math* […] *I promote my learning by solving problems. When you are able to solve problems it means you learned the content. Reading the text helped me to learn. Reading the text and solving problems are related to each other.*"

In the post-interview, she described the reflective writing activity as a self-learning physics methodology. She found it helpful since it made her read the book, explain the concepts in her own words and also think about the application of principles in real life and the relationship among various physics concepts:

> "*They* [reflective writing assignments] *helped me compare what I knew with what read. They also helped me review each lecture after being taught and were also helpful in solving problems since you need to know the materials to be able to answer the question and solve the problems. They made me find out which parts are difficult and I actually came up with many questions. I think asking questions help understanding. They made me use my logic and analyze the concepts rather than memorizing what the professor taught in the class. I thought about the real life applications of the concepts and the possible connections that exist between the physics laws.*"

She appreciated reflective writing as an activity that made her think about what she knew and what she had experienced before. Writing about each lecture after being taught helped her in solving problems. Reflective writing also provided an opportunity for Student E to find out which parts of the book were difficult and as a result she came up with many questions for her instructors. She used reasoning and reread the book and her notes to address her questions. She also had the opportunity to talk about her questions with the lab instructor. Student E believed that providing a reflective writing assignment about the concepts that were going to be discussed in the labatorial, improved her performance in the lab:

> "*I was ready before doing each experiment. I knew what the experiment is about because I had worked on the concepts. If I didn't understand any part of the textbook, it was a great opportunity to ask my questions in the lab. I think I did a better job in the lab than*

the other ones in my group who didn't take the writing assignments seriously."

7.6 Student F

Student F did not enjoy writing and believed that writing did not help him learn the physics concepts. In the pre-interview he explained that just the reading part of a reflective writing activity is helpful not the writing part. He believed that the writing part of the activity wasted his time:

> "*It is helpful to be prepared before doing each lab. They* [reflective writing assignments] *make students read the book. But for someone like me who reads the book I think it is just a waste of time. I don't learn by writing... I don't learn by writing. I learn when I listen to someone or I watch something. It is just a waste of time. But it is good that it makes us read the book and follow the class.*"

He was not able to think about the application of physics concepts in real life and it took a long time for him to come up with some examples to explain the concepts in the first writing assignment. He believed that he gained understanding when he listened to someone explaining the concepts. This is the reason he did not take notes in the class and just listened to the course instructor and copied the notes of one his friends after each class. The only aspects that he appreciated about reflective writing were the motivation to read the book and following the class.

His ideas about reflective writing did not change during the semester, as we found in his post-interview when he stated:

> "*I am not a fan of writing. I learn when I listen not when I write. Writing assignments are definitely helpful but they were not very helpful to me. It was great to have an activity to*

make us read the book, understand the concepts and follow the class. It was also great to know the concepts before doing the experiments. But I am not a fan of writing. I enjoyed reading more.”

In the post-interview he explained that even if he was not able to come up with real life examples related to physics concepts, thinking about the examples provided by the course instructor simplified the complicated concepts and he gained a better understanding. He appreciated the fact that Phys1201 course and lab instructors emphasized the application of physics concepts in real life:

“*Well I found that teachers in physics department really care about real examples. I can’t think of good examples, but when Alexis* [Student F’s course instructor] *talked about real examples it simplified the complicated concepts. I know that thinking about the application of theories in life helps a lot but I honestly can’t provide good examples. But I became better by the end of semester... I understood the concepts better when Alexis talked about real life situations and so I found real examples helpful. We were supposed to provide examples in the lab. I couldn’t come up with great examples but other students in the group could. I thought about their examples and they made sense... I learned the concepts better when Alexis explained Newton’s third law. It didn’t make sense to me when I read it. It was just meaningless. Seemed like something that I needed to memorize. But when he talked about opening a door it made perfect sense. But you know I could never think of the door example. But when Alexis explained it made perfect sense. You don’t fall when you push a door.*”

7.7 Student G

Student G explained that she thought she learned all the concepts in the class, but she came up with many questions when she reviewed her notes and read the textbook. She believed that reflective writing helped her think deeply about the physics concepts and the relationships among them. She also found many explanations and details in the book not covered in the class due to time restrictions:

> "*It is good to write about the principles taught. When I sit in the class I get the material but when I review my notes and read the book many questions come to my mind. Writing about what was taught helps me think deeply. There are also many steps and concepts not mentioned in the class. By reading the book and writing I learn more and more things. It is good to think about the application of principles and the way they are related to each other. It is important to know the relations among various concepts. I need to learn the meaning of the concepts and equations and learn how to connect them to be able to use the right ones in the problems.*"

Student G believed that thinking about the application of physics concepts in real life simplifies them and improves learning. She found the reflective writing rubric scary and detailed and was worried about addressing all the marking criteria in the pre-interview:

> "*I have completed one* [reflective writing assignment] *so far. I am concerned about marking. The marking table has many details and is a little bit scary. I tried to address all the marking criteria. I haven't received a feedback yet... I want to improve my experience with problem solving. I want to learn more about physics and I also want to get a great mark.*"

In the post-interview she explained that since reflective writing involves thinking and analyzing, she gained a better understanding of concepts after providing her writing assignments:

> "*I read the text and highlight the important themes and add notes to my class notes. That is why I found reflective writing assignments helpful. They were similar to what I do to study physics, biology and chemistry but they were more organized and I had to relate the concepts to everyday stuff. I needed to analyze the concepts recall them and write about them.* [Reflective writing] *helped me analyze each section and understand the material better.*"

She also found reflective writing helpful in answering the worksheets questions in the lab:

> "*Reading the material before doing experiments helped me come up with good questions. The lab instructor was approachable and answered all my questions. We reviewed the concepts at the beginning of each lab and writing assignments helped me in answering the worksheet questions.*"

Student G believed that when she read the materials before coming to the lab, she had more confidence to express her ideas in the lab and discuss the topics with the lab instructor and her peers: "*Reflective writing assignments increased my self confidence in the lab. When I knew the concepts before doing the experiments I was more confident to defend my opinions and discuss over the results gained.*"

7.8 The Reasons Why Reflective Writing is Helpful

The points mentioned by all interviewees provide a consistent picture that explains the reasons why reflective writing is helpful to students' learning in the Phys1201 course. These reasons can be classified into three broad categories: first, the development of a hermeneutic approach to the study of physics; second, the influence of reflective writing on learning skills; and third, the emotional influences of reflective writing on students.

The following points mentioned by interviewees encouraged a hermeneutic approach to the study of Phys1201 course:

1. Reflective writing values students' pre-knowledge and integrates them with new information.
2. It involves thinking, comparison, reasoning, and explaining
3. It reinforces the use of physics principles in real world situations.
4. It helps explore the relationship among various physics concepts

Students' learning and thinking skills and strategies evolve during the school year. It is important to help them discover how to manage their own learning and acquire knowledge and skills that they can transfer to a variety of situations related to learning, work and daily life. We aim to help students develop the habits and skills they need in order to become self-directed, independent learners. The following points mentioned by interviewees are related to learning skills:

1. Reflective writing makes students read and engage with the textbook
2. It improves students' understanding of the concepts
3. It improves students' problem solving skills
4. It improves student engagement

5. It results in a better performance in the lab

The points mentioned by interviewees related to the effect of using reflective writing in labatorials on learning skills are related to students' perspectives on knowledge and learning. Chapter 9 focuses on the epistemological results gained in fall 2014.

Based on interviewees' perspectives on reflective writing and also the comments left by students I found that reflective writing activity has had emotional effects on students. The following points mentioned by the interviewees and the students enrolled in Phys1201 labs are related to emotional influences of reflective writing activity:

1. Reflective writing creates motivation to read the textbook
2. It decreases students' anxiety
3. It improves self-esteem and self-confidence

A brief overview of Kalman and his research group was presented in Chapter 1(Section 1.5.2.5). In this project, we probed deeper into students' perspectives on labatorials and the reasons why this learning activity leads to effective students' learning outcomes. Kalman (2009) concluded that reflective writing provided teaching-learning opportunities for building strategies to improve the quality of thinking about physics phenomena. This conclusion is very broad and doesn't provide any detail explaining the strategies that improve the quality of thinking. In this chapter, we probed the students' underlying motivations and approaches to learning in an effort to explain why reflective writing is helpful and the reasons why it improves students' learning skills. We classified the themes gained into three broad categories: First, reflective writing provides an opportunity for students to approach science in the manner of hermeneutics. This category is consistent with the analysis of students' perspectives on pre-understanding that shows reflective writing expands students' possibilities of using pre-understanding and helps them expand their horizons. Second, reflective writing affects students' learning skills by improving students' understanding of concepts, problem solving skills, engagement and performance in the lab. Third, the emotional effects of reflective writing include motivation to read the textbook and lowering students' anxiety.

In Chapter 8, we will discuss the points mentioned by interviewees explaining the reasons why labatorials are helpful in learning Phys1201

Chapter 8: Students' Perspectives on Labatorials

There are publications providing an introduction to labatorials and explaining how they work (Ahrensmeier, 2013; Ahrensmeier et al., 2012). There has not been any research done to find out students' perspectives on labatorials and also discussions of their positive and negative aspects of them. In this chapter a case study on labatorials is presented along with their advantages and disadvantages. There are many points mentioned by the interviewees (Students A, B, C and D in winter 2014; and Students E, F, and G in fall 2014) explaining why they found labatorials helpful. However, some points are not specific to the characteristics of labatorials and thus these points are relevant to traditional laboratories as well. For instance hands on experiment, group work, seeing the application of principles and concepts in the lab are the positive aspects of both traditional labs and labatorials. Therefore, in this chapter I try to focus on the specific characteristics of labatorials that make this new style of laboratory helpful.

8.1 Student A's Perspectives on Labatorials

In the pre-interview Student A appreciated the conceptual questions at the beginning of each lab. He believed that labatorials take students step by step and help them to perform the experiments. He called the conceptual questions, problems and simulations at the beginning of each labatorial worksheet a "warming up section" and explained that the warming up activities assist students in thinking about what they learned in class and what they already knew before doing experiments. He also liked that fact that labatorials provide an opportunity for students to compare their experimental results with the theoretical knowledge and what they expected. Student A believed that group discussion in labatorials lowered his anxiety since he knew that there were three other students in his group who would help him if he did not know the answers to the conceptual questions and also they didn't lose any marks if the answers were wrong. The marking criteria, which is that full marks are given to all students who complete the worksheet by the end of the lab gave him confidence to express his ideas about physics concepts in the lab without being worried about losing marks. He explained that he was so relaxed in the lab and the atmosphere was informative, and friendly. Each labatorial emphasizes on the application of physics concepts in real life and Student A believed that this makes the Phys1201 course more interesting. Student A also valued the fact that he didn't need to prepare a laboratory report which he believed is time consuming and not helpful.

In the post-interview Student A emphasized the role of labatorials in understanding the physics concepts. He believed that the conceptual questions in each worksheet helped him think about the meaning of concepts and their application in real life. He explained that labatorials helped him think about the relationship among various physics concepts since in some experiments they needed to use their knowledge of previous labs to be able to do the experiments and analyze the results. He believed that both reflective writing and labatorials were effective ways to learn concepts.

8.2 Student B's Perspectives on Labatorials

When I was talking to Student B in the pre-interview, he had completed two labatorials. He really liked the checkpoint system and explained that his work was checked three to four times during the lab and the instant feedback kept him and the other students in his group on the right track. He found it too early to judge labatorials in the pre-interview, but he believed that any activity that provides an opportunity for students to see the application of theories in real life is always helpful. He explained that he gained a better understanding of concepts when he sees their application in life.

In the post-interview, Student B explained that labatorials helped him gain a better understanding of concepts. The conceptual questions at the beginning of each worksheet helped him think about the concepts and then he saw their applications while doing the experiments. He enjoyed the group discussions and found it helpful to hear the explanation of the concepts from his peers rather than professors. He explained that it is always great to hear other perspectives and discuss them in a friendly way and appreciated the friendly and relaxed environment that labatorials created. He also believed that there was enough time in each lab to think about the questions and the outcomes of the experiments. The relationship among various labs was also another positive point that made Student B gain a better understanding of concepts and the relationship between them.

8.3 Student C's Perspectives on Labatorials

In the pre-interview Student C had completed two labatorials. She believed that the first two labatorials included a variety of activities such as conceptual questions, problems, PhET simulation (please see Section 1.4) and students' predictions of the experiments' outcomes that make the group work and experimental work more interesting and helpful. She believed that working on the concepts first and then doing the experiments related to them helps students get a better understanding of concepts and also improve students' performance in the lab.

In the post-interview Student C emphasized that she really enjoyed labatorials. She explained that since she needed to do the writing assignments before coming to the laboratory she had a good understanding of the concepts before doing the experiments and this helped her in the analysis of the results of the experiments. She believed that the questions at the beginning of each labatorial worksheet helped her understand the concepts better.

8.4 Student D's Perspectives on Labatorials

In the pre-interview Student D explained that he liked the group discussions and the checkpoint system. He found it very helpful to hear other students' views and discuss the questions in a friendly environment. He appreciated the checkpoint system that provides instant feedback in the lab and explained that preparing a lab report takes a long time and students receive feedback one week after doing the experiments. He believed that a written feedback including the comments of a lab instructor is not as effective as the verbal feedback that students receive in labatorials.

In the post-interview, Student D explained that he found labatorials helpful because they gave him a chance to express his ideas and test them. This made him think about what he learned in the class and relate them to the experiments. He emphasized that labatorials played a significant role in understanding the physics concepts. He really liked the conceptual questions at the beginning of each worksheet that were related to the experiments.

8.5 Student E's Perspectives on Labatorials

In the pre-interview Student E explained that she didn't have confidence to mention what she thought about questions in the class. She never answered the professor's questions in the class since she found it embarrassing if her answer was not right. However, what she liked about labatorials was discussing her ideas with her peers. She believed that she had more confidence to talk about physics among the students who have the same level of physics knowledge as her. She didn't find it tough to discuss the questions with the lab instructor since they were working in groups and she was not the only person responsible for the wrong answers. She found the discussions with peers and lab instructor very helpful in learning physics.

In the post-interview Student E appreciated the conceptual questions, simulations and the problems included at the first section of the worksheet. The pre-experiment activity made her think about what she knew and what she learned in the class and the predictions that she needed to make before doing the experiments made her think about the concepts and the outcomes of the experiment. She found this challenging and explained that these challenges made labatorials more interesting. She believed that labatorials encourage communication and this made it easy for her to ask her questions and express her ideas. Students E liked the experiments that were related to each other. She needed to use what she learned in the previous labs to be able to do the experiment and also answer the conceptual questions.

8.6 Student F's Perspectives on Labatorials

Student F enjoyed labatorials a lot. He emphasized the fact that he learned the materials better when someone explained them to him. He didn't take notes in the class because he wanted to focus on the instructor's explanations of concepts. In the pre-interview he said that students explain the concepts in a simple way and he learned a lot when a peer explained the materials to him. He enjoyed the conceptual questions at the beginning of each labatorial worksheet since all students in one group needed to have the same answers and this made them explain their ideas to each other and discuss the questions. He appreciated the explanatory nature of labatorials and the pre-experiment activities such as simulations and making predictions.

In the post-interview, Student F had similar opinions about labatorials. He liked the layout of the labatorials that focus on the concepts first and there are various activities related to the concepts before doing the experiments. He believed that instant feedback is the most important aspect that makes labatorials helpful and enjoyable. He explained that writing a lab report is time consuming and students are not given a chance to defend their ideas and discuss the comments left on their lab reports.

8.7 Student G's Perspectives on Labatorials

Student G had completed the first two labatorials when we had our pre-interview. She found it too early to judge labatorials, but explained that she liked the conceptual questions at the first part of the labatorials worksheets. She also believed that labatorials made a relaxed atmosphere in which students were able to express their ideas and discuss the questions.

In the post-interview she explained that she gained a better understanding of concepts since simulations, conceptual questions and predictions students made before doing experiments made her think deeply about the concepts. She believed that labatorials encouraged students' participation and the checkpoint system initiated communication with the lab instructor. She appreciated the checkpoint system that provided instant feedback and helped them stay on track. She believed that labatorials provide an opportunity for students to defend their opinions, while in the traditional laboratories students receive a written feedback on their lab report one week later. She believed that the first part of each labatorial makes students work on formulas and concepts and the experimental part helps them use them in a real situation. Labatorials helped her to become articulate about her knowledge and gain a better understanding of the concepts through explaining them, discussing them and applying them in the experiments.

8.8 The Reasons Why Labatorials are Helpful

The points mentioned by all interviewees explaining the reasons why labatorials are helpful in learning Phys1201 course can be classified into two broad categories: first the influence of labatorials on learning skills, and second the emotional influences of labatorials on students.

It is important to help students discover how to acquire knowledge by doing experiments and develop the habits and skills they need in order to become independent learners. The following points mentioned by interviewees are related to learning skills:

1. Labatorials values students’ ideas and pre-knowledge; and integrate them with the experiments.

2. They involve thinking, comparison, reasoning, and explaining

3. They help explore the relationship among various physics concepts

4. They provide instant feedback

5. They improve student engagement

6. They improve students’ understanding of the concepts

The first two points are highly related to each other. Labatorials ask students to make predictions and this values their pre-knowledge and their opinion. This makes them feel that their opinions are important and labatorials will integrate their beliefs and knowledge with the experimental results gained. Students need to compare their predictions with the experimental results gained and discuss whether or not the results support their predictions. This process involves thinking, comparison, reasoning, and explanation. I asked the interviewees to explain their perspectives on the prediction part of the labatorial activity. Tables 8.1 and 8.2 show the statements that interviewees made about the "prediction process" of labatorials.

Interviewee	Interviewees' opinions about the "prediction process" of labatorials
A	"Labatorials involve understanding the questions, hypotheses, observations, and analysis to make conclusions. Making predictions helps you think through the various possibilities and come up with an answer to the original question. I like the "hypothesis" part since this part makes you think about what you already know. Labatorials combine your knowledge with the experiments. You don't sit down to prove what you learned in the class. You think about what you know and write down what you think you will find based on your knowledge. In labatorials, experiments are the tools that test your predictions. Your prediction matters and this process also makes the experiments more interesting."
B	"Each labatorial is like a small project. There is a question and you need to understand it first. I like the "prediction section" very much. It makes you understand the question better and actually think about what you already know about the question. Making prediction involves thinking, discussion and judgement. I found the writing assignments very helpful at this stage of the experiments because you need to come up with a possible solution based on what you already know about the experiment question."
C	"In the prediction section you propose an answer to the labatorial question based on what you know. The prediction parts of the labatorials involved thinking and reasoning when I spent a great deal of time on the reflective writing assignments. I actually didn't care much about the reflective writing assignments at the beginning of the semester and, as a result, for the first labatorials I just guessed something and wrote it down to fill up the prediction section without reasoning. But after the second midterm I started spending a great deal of time preparing my reflective writing assignments and making sense of the book sections related to the labatorials and I actually thought about what I had learned and used thinking and reasoning to come up with a reasonable possible solution."
D	"The prediction parts make you think about what you already know and try to combine your knowledge with your observations and the results of each experiment. What I like about labatorials is that you shouldn't change your predictions, even if the experimental results show that you were wrong. I think this is what scientists do. I remember I performed the projectile motion experiment several times to find out why the results don't match my predictions. Finally, I realized that the launching level was higher than the landing level and this was the reason I didn't get what I expected. My predictions were actually right, but the experimental situation was different from the situations that I based my predictions on."

Table 8.1 Interviewees' perspectives on the "prediction process" of labatorials in fall 2014

Interviewee	Interviewees' opinions about the "prediction process" of labatorials
E	"In the labatorials I learned that an incorrect prediction doesn't mean that you are wrong. There were some labatorials in which my predictions were not supporting the numerical data gained. It was because I didn't think about the factors that would affect the experiment and I expected to get the same results as what I predicted without considering these factors. For example, for Newton's second law, the track wasn't level and the values of the acceleration after increasing the cart's mass didn't match what I expected. The prediction parts of the labs involve thinking about what you already know and comparing your predictions with the experimental results also involves thinking, comparison and judgement."
F	"I didn't learn anything in high school and for the first labatorials I wasn't confident enough to make predictions based on what I knew. But I learned a lot of new stuff during the semester and also the reading part of the writing assignments helped me make reasonable predictions in the last four labatorials. I learned many new concepts in the lab that I hadn't thought about before. I like the fact that you don't change your predictions in the lab. Instead, the lab instructor wants you to explain what might have been wrong that your predictions don't support the results of the experiment. This motivated discussion and explanation in our group. In general I think the prediction parts of the labs are designed to motivate thinking, explanation, discussion and comparison in the lab."
G	"Making predictions made me think about what I learned in the class. I also used what I learned from the text and my own personal experiences to anticipate the results of the experiments. This [the prediction] process involves thinking ahead and also helps students make connections between their prior knowledge and what they observe and perform in the lab."

Table 8.2 Interviewees' perspectives on the "prediction process" of labatorials in winter 2015

All interviewees believed that reflective writing was one of the resources that helped them make predictions about the outcomes of the experiments in the lab. The "prediction process" of labatorials motivated the doubt, humility, and strength dispositions that we discussed in Section 1.6. The development of such dispositions encourages a hermeneutical approach to science and helps students move towards having a more expert-like epistemology about science and knowledge.

All interviewees appreciated the instant feedback provided in labatorials. Prior to the introduction of labatorials, introductory courses contained tutorials and traditional physics labs with a focus on experimental physics techniques and data analysis. In traditional labs, students were required to prepare a lab report, which was handed in to the lab instructor, marked, and returned the following week. Therefore, students received feedback after the course material had progressed to another topic. In addition, there was no incentive to review comments or to work out the correct answers. By using the highly interactive labatorial method, students can find the correct answer in the lab and they do not write a report after doing the experiment. As explained before, most interviewees believed that providing a lab report is not beneficial and takes a long time. Labatorials provide ongoing feedback that is advantageous both to students and to instructors during the semester. They help students identify their strengths and weaknesses and target areas that need work. It also helps faculty recognize where students are struggling and address problems immediately. This assists students in gaining a better understanding of concepts. Labatorials enforce conceptual understanding by providing formative feedback to students and instructors. The labatorial checkpoint system increases the interaction between the students and the lab instructor. In Chapter 1 we presented Vygotsky's model which explains that teacher guidance and collaboration with peers can help students in solving a higher-level problem (Vygotsky, 1980; Kalman, 2006). We also reviewed the developmental stages presented by William G. Perry: dualism, multiplicity, relativism, and commitment (Perry 1999). For example if our students in the introductory physics labatorial are at the dualism stage, these students on their own can deal with the learning tasks at the level of the duality developmental stage. By providing instant feedback and guidance or by encouraging collaboration among peers we can enable these students to solve a higher level problem (e.g., a problem at the level of multiplicity). All interviewees valued the discussions happening among the peers over the labatorials' activities and also the interaction with the lab instructor. Labatorials encourage students' participation and discussions among peers which based on Vygotsky's model improve students' understanding of concepts and help them deal with higher-level questions. Therefore, the last point mentioned by interviewees, "labatorials improve students' understanding of the concepts", is highly related to the first 5 points mentioned. One of the reasons to change old style labs to labatorials was to emphasize the physics concepts taught in the lecture by designing conceptual questions and activities in the first part of each labatorial worksheet.

Old style laboratory weekly reports require a great deal of investment in terms of student time and staff time. In many universities, increasing class sizes makes the marking of weekly lab reports challenging. In addition to save a considerable amount of staff time by using labatroials, one of the main objectives of this report-free style of lab is to improve a variety of skills in the students, such as self-directed learning, critical reasoning, reflection, negotiation, professional judgment, teamwork, and self-awareness, and increase confidence which will be helpful in future collaborative work. The following points mentioned by the interviewees and the students enrolled in Phys1201 labs are related to emotional and social influences of labatorials:

1. Labatorials integrate communications and discussions in a friendly environment.

2. They decrease students' anxiety.

3. They improve self-confidence.

All interviewees appreciated the opportunity that labatorials provided for students to express and defend their ideas in a friendly environment. Discussing over questions, listening to the other students' opinions and also defending one's own ideas are not only helpful in learning physics, but also in future collaborative work and social life.

We found that labatorials improved student satisfaction and this was one of the important goals that we achieved by using this new style of lab. The grading process for labatorials focuses on guiding the students to eventual conceptual understanding rather than worrying about getting answers 'correct' initially. As such, full marks for a labatorial exercise are granted to all students who complete the full worksheet by the end of the lab period, regardless of whether or not initial answers were 'correct' and whether or not guidance by the lab instructors was required. If the answer to a worksheet question is incorrect, the lab instructor engages with the students to help guide them towards a logical path to allow them to find the answer or the concept themselves. Thus they are allowed, in fact encouraged, to explore and discuss alternative methods without the threat of losing marks. This has improved student satisfaction and has lowered student worries about marking and expressing ideas. As a result students have more confidence to discuss and defend their opinions. An increase in students' satisfaction facilitates a positive learning environment.

Most comments left by students and the interviewees' statements about labatorials are encouraging. For example:

> "*Labatorials are very helpful in the fact that they show us real examples of something we don't understand, to make it easy to understand and comprehend,*" and "*Labatorials help me understand the material much better than the actual lecture section does,*" and " *I love the way the labatorials explain concepts, it's been very useful for increasing my understanding. The classes go very smooth and everyone is progressing,*" and "*The*

labatorials are very helpful, I really appreciate that there are no lab reports and that we are encouraged to work in groups. They make concepts easy to understand and I wish the other course labs were like labatorials."

8.9 Challenges of Using Labatorials

It was a big change to replace the old style physics laboratories with labatorials with the transition creating many challenges, which are described in this section along with the solutions used to overcome them. We established weekly meetings for lab instructors to get familiar with labatorials and the desired goals. At MRU there is only one lab instructor in each 16-student lab section (the original University of Calgary implementation used 4 instructors for 48 students), which sometimes resulted in student groups who have completed a labatorial section waiting while the lab instructor completes a checkpoint section with another group. This delays the laboratory and some students find it frustrating. Some feedback we have received from students is that they would prefer groups of 2 or 3 members as most of the time not every member of every group participates, making checkpoints difficult and frustrating. However, because we have just one instructor in each lab, a larger number of smaller groups would not be practical. We decided to use a writing method in the lab at each checkpoint. In winter 2013, we asked students enrolled in Phys1202[8] to provide a brief report of the concepts and activities covered at each checkpoint. Students moved to the next checkpoint while the lab instructor reviewed the students' reports. This decreased the verbal interaction between students and lab instructor. Preparing a written report at each checkpoint took a great deal of lab time and students didn't

[8] Phys1202 provides an introduction to fluids, thermodynamics and electromagnetism. The topics covered include: pressure, Pascal's and Archimedes' principles, temperature, the ideal gas law, the laws of thermodynamics, electric forces and fields, electric potential, electric currents and circuits, and magnetic forces and fields.

have enough time to think about the labatorial activities and the results gained. I also interviewed three students in winter 2013 and they all found the report activity frustrating and stressful. They did not find the report activity beneficial and we have since discontinued use of the written summary method since its one trial implementation. These students did not show up for the post-interview and I did not use their pre-interview transcripts in this study. Written summary checkpoints were not used in the labatorials in the course offerings studied in this project. We intend to continue the combination of labatorials and reflective writing activity in introductory physics courses at MRU. It is our goal to improve the conceptual questions and design more experiments to increase the efficiency of the labatorials.

Chapter 9: Analysis of Students' Learning Strategies and Epistemology

We have discussed that during the years of schooling, students' learning strategies and their epistemologies about knowledge and learning evolve. The way the knowledge is presented through the times at school affects students' understanding of it. If science is presented to students as a body of settled facts, and absolute truths, then students will focus on memorizing facts. If, on the other hand, students experience science as a continuous process of concept development, an interpretive effort to determine the meaning of principles, and a process of negotiating these meanings among individuals, then they might focus on concepts and reasoning rather than memorizing (Stodolsky, Salk, & Glaessner, 1991). Since we believe that students' reasoning and making sense of the concepts are a vital part of reflective writing activity and labatorials, it was important to explore whether the combination of reflective writing and labatorials can change students' ways of learning and their views of knowledge during the semester. This part of the thesis focuses on the epistemological results gained in fall 2014. As discussed in Section 4.2, we used the discipline-focused epistemological beliefs questionnaire for physics developed by Hofer (2000) in this study. In Chapter 3 we argued that Hofer (2000) explored discipline focused epistemological beliefs by having 326 first year college students. Students completed two versions of a discipline focused epistemological beliefs questionnaire, one for psychology and one for science. Students rated each of the 27 items on a 5-point scale (1 =strongly disagree; 5 = strongly agree). The results suggested a four-factor model for each discipline (Appendix B). These factors represent the 'certain/simple knowledge' factor (eight items), 'justification for knowing' factor (four items), 'source of knowledge: authority' factor (four items), and 'attainability of truth' factor (two items). Table 9.1 shows that for the 'certain/simple knowledge' factor, 'source of knowledge: authority' factor, and 'attainability of truth’ factor a low score indicates more expert-type reasoning, while for the ‘justification for knowing’ factor a high score points out more expert-like way of thinking. Figure 9.1 shows the direction of change from a novice-like reasoning to an expert-like way of thinking for each factor. To determine whether epistemological change can be achieved as a result of combining reflective writing and labatorials, we designated two groups in fall 2014: an experimental group and a control group. In fall 2014, eight Phys1201 lab sections were assigned to do reflective writing, while the remaining seven Phys1201 lab sections provided summary writing. There were 110 students in the experimental group who did reflective writing and 102 students in the control group who provided summary writing products during the fall 2014 semester. The results of the comparison between the experimental group (students who did reflective writing) and the control group (students who did summary writing) are presented in this chapter. The statistical test chosen to address this purpose was the paired t-test. In a paired t-test, a null hypothesis indicates that there is no difference between variables (Mowery, 2010). The null hypothesis for our study states that there are no differences between the students’ responses to the disciplined-focused epistemological beliefs questions (Hofer’s survey) at the beginning and end of the fall semester. Therefore, a null hypothesis indicates that the combination of reflective writing and labatorials didn’t change the students’ epistemological beliefs about the nature of knowledge and knowing. The significance level (or p value) is used to measure the probability that the null hypothesis is true. The p value ranges from 0.00 (0% probability that the null hypothesis is true) to 1.00 (100% probability that the null hypothesis is true). The results of paired t-tests for each factor are presented in this chapter. Table 9.2 and Table 9.3 show the p value of each factor for the experimental and control groups respectively. The data presented in Table 9.2 and 9.3 are plotted as a bar graph in Figures 9.2, 9.3, 9.4, and 9.5.

Factor	High Score	Low Score
Certain/Simple Knowledge	Novice-like reasoning	Expert-like reasoning
Justification for knowing	Expert-like reasoning	Novice-like reasoning
Source of Knowledge: Authority	Novice-like reasoning	Expert-like reasoning
Attainability of Truth	Novice-like reasoning	Expert-like reasoning

Table 9.1 The relationship between the score and the way of thinking for each factor

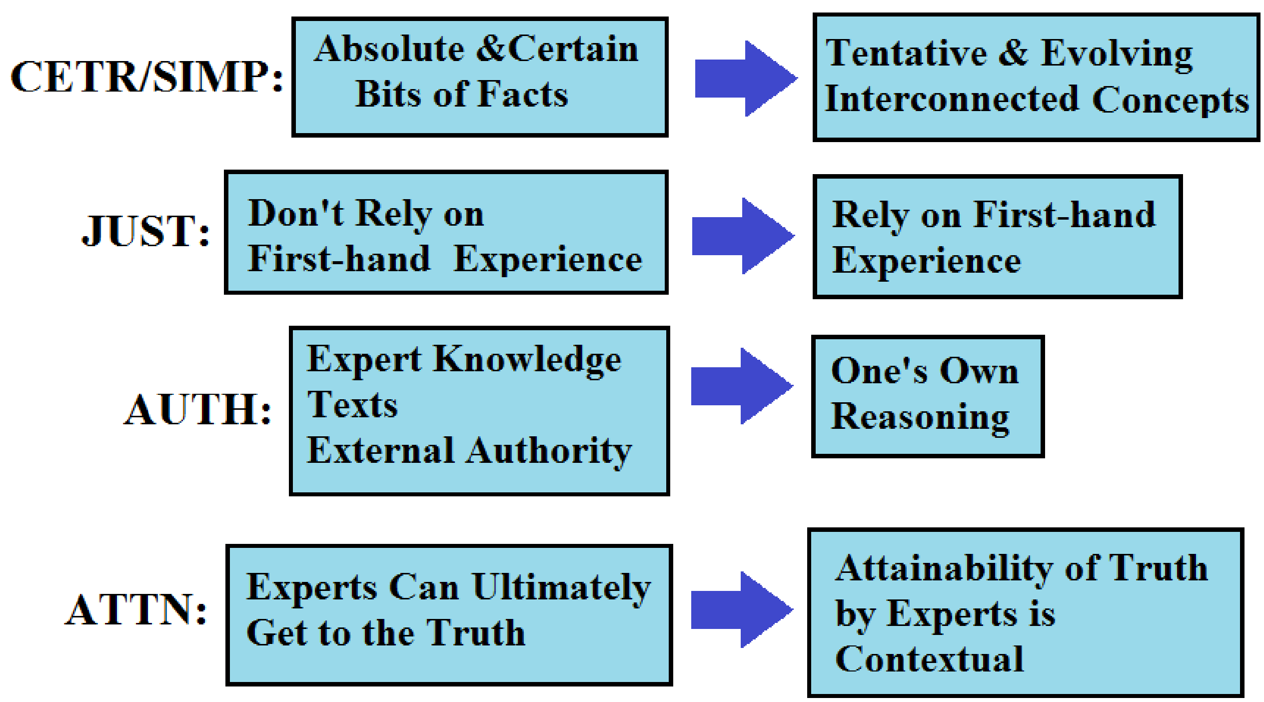


Figure 9.1 The direction of change from a novice-like reasoning to an expert-like way of thinking for each factor

Factors	Mean Pre-test	Mean Post-test	N	Paired Differences (“Pre-test” – “Post-test”)			t	Sig. (2-tailed)
				Mean	Std. Deviation	Std. Error Mean		
Certainty/simplicity	3.76	3.33	110	0.436	0.290	0.0276	15.8	0.000
Justification: personal	2.17	1.96	110	0.214	0.386	0.0368	5.81	0.000
Source: authority	3.88	3.33	110	0.557	0.598	0.0570	9.77	0.000
Attainability of truth	4.02	4.01	110	0.014	0.644	0.0614	0.222	0.825

Table 9.2 The results of paired t-test for the experimental group

Factors	Mean Pre-test	Mean Post-test	N	Paired Differences (“Pre-test” – “Post-test”)			t	Sig. (2-tailed)
				Mean	Std. Deviation	Std. Error Mean		
Certainty/simplicity	3.81	3.60	102	0.218	0.344	0.0341	6.40	0.000
Justification: personal	2.34	1.83	102	0.510	0.745	0.0737	6.92	0.000
Source: authority	3.90	3.42	102	0.480	0.694	0.0687	7.00	0.000
Attainability of truth	3.88	3.91	102	-0.0245	0.794	0.0786	-0.312	0.756

Table 9.3 The results of paired t-test for the control group

9.1 Analysis of 'Certainty and Simplicity of Knowledge' Factor

As can be seen in Figure 9.2, there is a statistically significant epistemological change in both control and experimental groups regarding the 'certainty/simplicity of knowledge' factor. We compared the experimental group with the control group to see whether the combination of labatorial and reflective writing activity had any effect in epistemological change of 'certainty/simplicity of knowledge' factor. A one-way ANCOVA (analysis of covariance) was conducted to confirm a statistically significant difference between the experimental group and the control group on the post-test controlling for the pre-test. The combination of reflective writing and labatorials has a significant effect on the post-scores of the epistemological test after controlling the pre-test scores, $F = 28.573$, $p<0.05$. Table 9.4 shows the statistical results of a pair wise comparison that we ran.

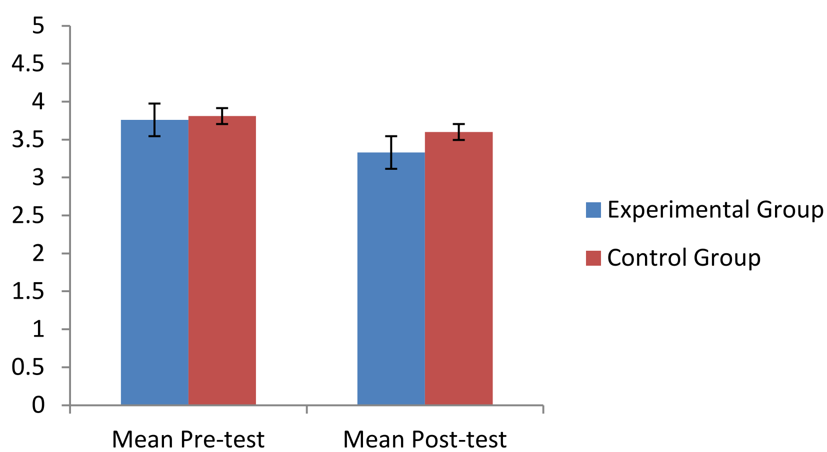


Figure 9.2 Mean pre- and post-score of 'certainty/simplicity knowledge' factor for experimental and control groups with standard error

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% confidence Interval for Difference	
					Lower Bound	Upper Bound
Cont	Exp	0.231	0.043	0.000	0.146	0.317

Table 9.4 A pair wise comparison between the experimental group and the control group for the 'certainty/simplicity of knowledge' factor

As can be seen in Table 9.4, change between experimental and control groups is significant. The null hypothesis for our study states that there is no significant difference between the experimental group and the control group. Therefore, a null hypothesis indicates that the combination of labatorials and reflective writing didn't affect the students' epistemological beliefs about the certainty and simplicity of knowledge. The significance level (or p value) is used to measure the probability that the null hypothesis is true. As can be seen in Table 9.4 the p value (Sig.) is 0.00 which shows that the hypothesis is not true. Therefore, the difference between experimental and control groups is significant and the combination of reflective writing and labatorials influenced the students' beliefs about certainty and simplicity of knowledge.

9.2 Analysis of 'Justification of Knowledge' Factor

Figure 9.3 presents a bar graph of average test scores of 'justification: personal' factor for both experimental and control groups. As can be seen in Figure 9.3, there is an epistemological change in opposite direction for both control and experimental groups regarding the 'justification for knowing' factor. We compared the experimental group with the control group to see whether the combination of labatorial and reflective writing activity had any effect on this factor. A One-way ANCOVA was conducted to determine if a statistically significant difference exists between the experimental group and the control group on the post-test controlling for the pre-test. The combination of reflective writing and labatorials has a significant effect on the post-scores of the epistemological test after controlling the pre-test scores, $F = 8.254$, $p<0.05$. Table 9.5 shows the statistical results of a pair wise comparison that we ran. Similarly, as can be seen in Table 9.5, change between experimental and control groups is significant. The null hypothesis states that there is no significant difference between the experimental group and the control group. The p value (Sig.) is 0.004 which shows that this hypothesis is not true. Therefore, the difference between experimental and control groups is significant which means the epistemological change of ‘justification for knowing’ factor for the experimental group is less than the epistemological change that the control group experienced.

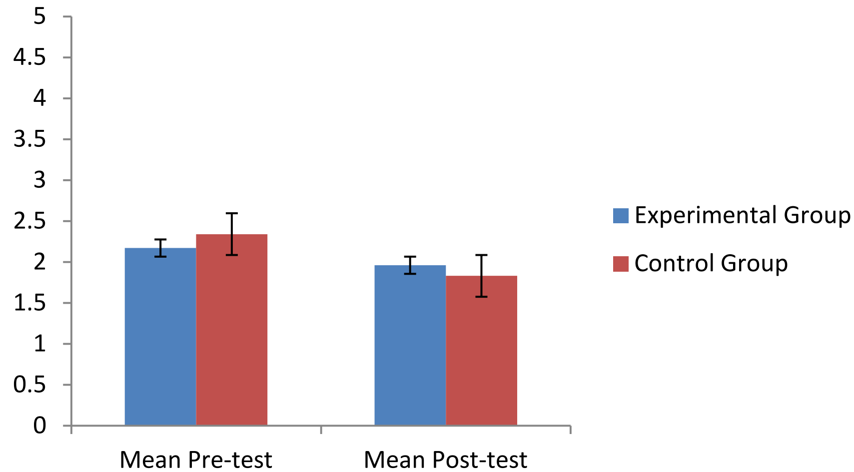


Figure 9.3 Mean pre- and post-score of ‘justification for knowing’ factor for experimental and control groups with standard error

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% confidence Interval for Difference	
					Lower Bound	Upper Bound
Cont	Exp	-0.199	0.069	0.004	-0.336	-0.063

Table 9.5 Pair wise comparison between experimental group and control group for ‘justification for knowing’ factor

9.3 Analysis of ‘Source of Knowledge: Authority’ Factor

Figure 9.4 presents a bar graph of average test scores of ‘source of knowledge: authority’ factor for both experimental and control groups. As can be seen in Figure 9.4, there is an epistemological change in both control group and experimental group. A One-way ANCOVA was conducted to determine a statistically significant difference between the experimental group and the control group on the post-test controlling for the pre-test. The combination of reflective writing and labatorials doesn't have a significant effect on the post-scores of the epistemological test after controlling the pre-test scores, F = 1.340, $p>0.05$. Table 9.6 shows the statistical results of a pair wise comparison. Similarly, as can be seen in Table 9.6, the change between experimental and control group is not significant. The mean difference is significant when the p value is less than 0.05, but as can be seen in Table 9.6 the p value is 0.248. The null hypothesis states that there is no significant difference between the experimental group and the control group. The p value (Sig.) is 0.248 which shows that this hypothesis is true. Therefore, the difference between experimental and control groups is not significant.

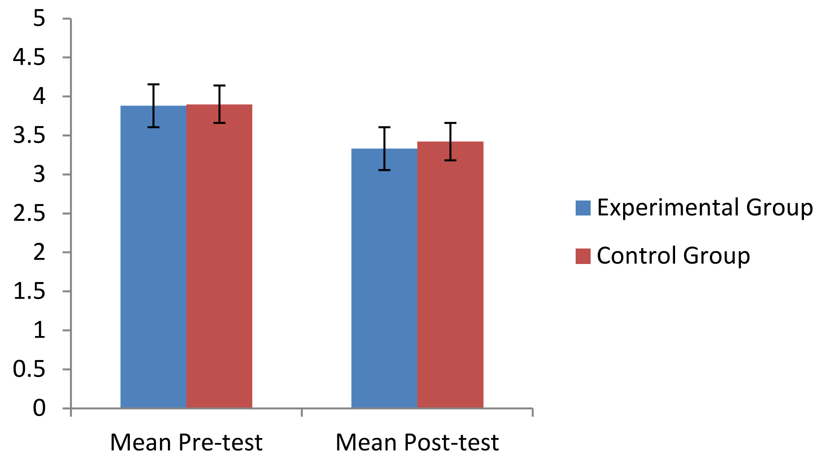


Figure 9.4 Mean pre- and post-score of 'source of knowledge: authority' factor for experimental and control groups with standard error

(I) Group	**(J) Group**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**	**95% confidence Interval for Difference**	
					Lower Bound	**Upper Bound**
Cont	Exp	0.88	0.076	0.248	-0.062	0.237

Table 9.6 A pair wise comparison between the experimental group and the control group for the 'source of knowledge: authority' factor.

9.4 Analysis of 'Attainability of Truth' Factor

As can be seen in Tables 9.2 and 9.3, there is no epistemological change in both control and experimental groups regarding the 'attainability of truth' factor. Therefore, the combination of labatorial and reflective writing activity had no effect on this factor. Figure 9.5 shows the mean pre- and post-score of 'attainability of truth' factor for experimental and control groups. A One-way ANCOVA was conducted to determine a statistically significant difference between the experimental group and the control group on the post-test controlling for the pre-test. The combination of reflective writing and labatorials doesn't have a significant effect on the post-scores of the epistemological test after controlling the pre-test scores, $F = 0.447$, $p>0.05$.

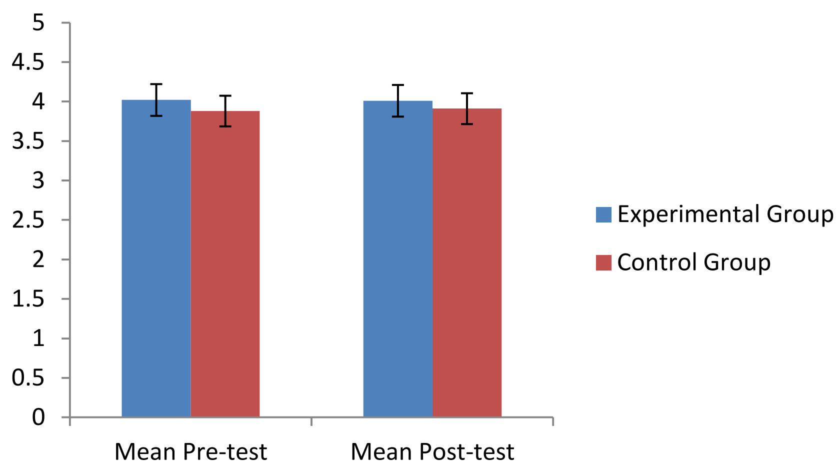


Figure 9.5: Mean pre- and post-score of 'attainability of truth' factor for experimental and control groups with 5% error bars

9.5 Epistemological Results of the Interviewees and Students

We looked at the epistemological scores of Students E, F, and G who participated in the fall 2014 interviewees. Figure 9.6 shows the histograms of pre score minus post score of all students in the experimental group for each epistemological factor. The reference lines on the x-axis show the pre score minus post score results of Students E, F, and G. Interviewees' epistemological results are consistent with the epistemological results of 110 students contained in the experimental group. Table 9.7 shows the difference between the survey score of interviewees at the beginning and end of the semester (pre score minus post score) for each factor. As can be seen in Table 9.7, interviewees' epistemological changes are consistent with the general trend of the experimental group for each factor. The epistemological scores of interviewee F, who had the lowest number of writing assignments with reflective writing style, indicate a more novice-like way of thinking in comparison with interviewees E and G. This encouraged me to evaluate the epistemological scores of the cohort of 41 students for whom I had evaluated their reflective writing assignments (see Section 6.8) and had also completed the epistemological survey in fall 2014.

Tables 9.8 and 9.9 show the results of the evaluations. Columns R, S, and R/S indicate the number of writing assignments with reflective writing style, the number of writing assignments with summary style, and the number of writing assignments that contain both reflective and summary styles respectively. Tables 9.8 and 9.9 show that in general students who completed more than 4 writing assignments with reflective writing style, had a more expert-like way of thinking.

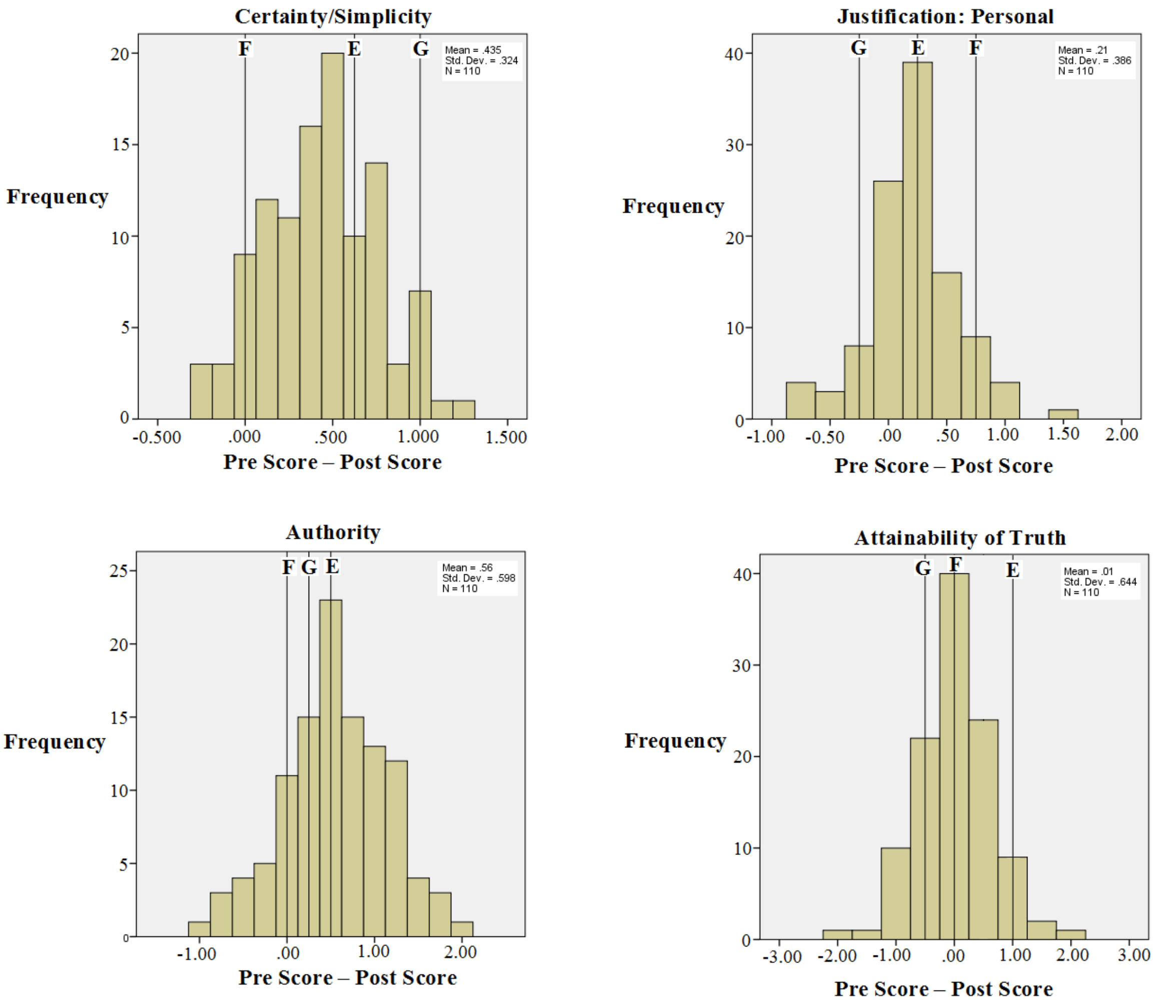


Figure 9.6: The frequency of difference between pre score and post score (pre score – post score) for each factor. The reference lines on the x-axis show the results for Students E, F, and G

Interviewee	**Certainty/Simplicity**		**Justification**		**Authority**		**Attainability**	
	Pre Score	Post Score	Pre Score	Post score	Pre Score	Post score	Pre Score	Post score
E	4.000	3.375	2.250	2.00	4.500	4.000	4.000	3.500
F	4.250	4.250	2.500	1.750	4.750	4.750	4.500	4.500
G	3.625	2.625	2.250	2.500	3.500	3.250	4.000	3.000

Table 9.7 Interviewees' pre- and post-scores of epistemological survey

Students	Cert/Simp		Just		Auth		Attn		R	S	R/S
	Pre Score	Post Score	Pre Score	Post score	Pre Score	Post score	Pre Score	Post score			
1	3.625	3.5	2.00	1.75	2.50	2.25	3.00	4.00	6	1	2
6	2.875	2.375	3.50	3.25	2.75	2.00	3.50	3.00	5	0	4
7	3.5	2.75	2.50	1.75	3.50	2.75	4.00	4.00	5	0	4
10	3.125	3.000	2.25	1.75	3.00	3.00	3.00	3.00	6	0	3
13	3.375	3.625	2.25	1.50	4.00	4.00	4.00	4.00	6	0	3
14	4.125	3.625	1.50	1.50	4.00	3.50	4.00	4.00	5	0	4
16	4.25	4.375	1.00	1.00	4.50	4.00	5.00	4.50	5	3	1
18	2.875	2.125	3.50	2.50	3.00	2.50	3.50	3.00	5	2	2
25	4.375	4	1.75	1.50	4.00	3.75	4.50	4.50	6	2	1
26	2.5	2.5	2.75	2.25	2.75	2.75	3.00	3.00	7	1	1
29	3.25	3.000	3.00	2.25	3.25	2.75	3.50	3.00	5	0	4
30	2.625	2.500	3.25	2.25	2.75	2.50	3.00	4.00	8	0	1
Average Score	**3.375**	**3.115**	**2.44**	**1.94**	**3.33**	**3.00**	**3.67**	**3.67**			

Table 9.8 The pre- and post-scores of epistemological survey of the students who had more than 4 writing assignments with reflective writing style

Students	Cert/Simp		Just		Auth		Attn		R	S	R/S
	Pre Score	Post Score	Pre Score	Post score	Pre Score	Post score	Pre Score	Post score			
3	4.125	4.125	2.00	1.50	4.75	4.25	4.50	5.00	0	6	3
5	4.000	3.625	1.75	1.75	4.75	4.00	4.50	5.00	3	4	2
8	3.5	3.375	2.00	2.00	4.00	3.00	4.00	3.50	2	5	2
9	4.125	4.125	2.00	1.50	4.75	4.25	4.50	5.00	0	8	1
11	3.875	3.375	2.00	1.75	4.50	5.00	5.00	5.00	0	6	3
12	3.875	3.250	2.50	2.50	4.50	3.50	4.50	4.00	3	2	4
15	4.25	4.25	2.25	1.75	4.50	3.25	5.00	5.00	3	4	2
19	3.875	4.125	2.00	1.75	3.25	3.50	4.50	4.00	0	7	2
20	4.25	3.25	1.75	1.50	4.25	4.00	5.00	4.00	3	0	6
22	4.25	3.625	2.25	1.75	3.25	3.50	4.50	5.00	2	4	3
23	4.25	4.125	2.25	2.50	4.25	3.75	3.50	4.00	3	4	2
24	4.000	3.375	3.25	2.00	5.00	3.25	5.00	4.00	2	4	3
27	4.25	4.125	1.75	1.75	3.75	2.5	3.50	4.00	0	6	3
Average Score	**4.048**	**3.75**	**2.13**	**1.85**	**4.27**	**3.67**	**4.46**	**4.42**			

Table 9.9 The pre- and post-scores of epistemological survey of the students who had less than 4 writing assignments with reflective writing style

Tables 9.8 and 9.9 are consistent with the study done by Huang and Kalman (2012). They found that students with higher scores on an epistemology survey (a higher score showed a more expert-like way of thinking in their study) tended to use reflective writing in a more effective way to enhance their learning of textual material.

9.6 Epistemological Results of the Students in Two Semesters

Students' epistemological beliefs change by time and studying changes in their beliefs of knowledge and learning can help us explore how students make meaning and how this can affect their learning. Many students who take Phys1201 course in the fall, take Phys1202 course in the winter. Phys1202 provides an introduction to fluids, thermodynamics and electromagnetism. The topics covered include: pressure, Pascal's and Archimedes' principles, temperature, the ideal gas law, the laws of thermodynamics, electric forces and fields, electric potential, electric currents and circuits, and magnetic forces and fields. Similar to Phys1201, students who take Phys1202 complete 9 reflective writing assignments during the semester. In winter 2015, there were 63 students enrolled in Phys1202 who had taken Phys1201 in fall 2014 and completed reflective writing assignments and took the epistemological survey. There were also 52 students enrolled in Phys1202 in winter 2015 who completed summary writing in fall 2014 and took the epistemological survey. To find out how students' epistemological beliefs change during two semesters, I gave these 115 students enrolled in Phys1202 course in winter 2015 an epistemological survey at the end of the semester. As can be seen in Tables 9.10 and 9.11, the epistemological results match the results of fall 2014.

Factors	Mean Pre-test	Mean Post-test	N	Paired Differences (“Pre-test” – “Post-test”)			t	Sig. (2-tailed)
				Mean	Std. Deviation	Std. Error Mean		
Certainty/simplicity	3.78	3.27	63	0.506	0.376	0.0474	10.7	0.000
Justification: personal	2.12	1.87	63	0.254	0.479	0.0598	4.24	0.000
Source: authority	3.87	3.38	63	0.488	0.556	0.0701	6.97	0.000
Attainability of truth	4.12	4.10	63	0.016	0.628	0.0792	0.200	0.842

Table 9.10 The results of paired t-test for the experimental group at the end of the winter semester 2015 (Post-test) compared to the beginning of the fall semester 2014 (Pre-test).

Factors	Mean Pre-test	Mean Post-test	N	Paired Differences (“Pre-test” – “Post-test”)			t	Sig. (2-tailed)
				Mean	Std. Deviation	Std. Error Mean		
Certainty/simplicity	3.72	3.59	52	0.135	0.338	0.0469	2.87	0.006
Justification: personal	2.32	1.73	52	0.591	0.786	0.1089	5.43	0.000
Source: authority	3.93	3.31	52	0.620	0.537	0.0744	8.33	0.000
Attainability of truth	3.79	3.81	52	-0.0196	0.685	0.0960	-0.204	0.839

Table 9.11 The results of paired t-test for the control group at the end of the winter semester 2015 (Post-test) compared to the beginning of the fall semester 2014 (Pre-test).

As can be seen in Tables 9.10 and 9.11, there is an epistemological change in both control and experimental groups regarding the ‘certainty/simplicity of knowledge’ factor over the period of two semesters. A One-way ANCOVA was conducted to determine a statistically significant difference between the experimental group and the control group on the post-test controlling for the pre-test. The combination of reflective writing and labatorials has a significant effect on the post-scores of the epistemological test after controlling the pre-test scores, $F = 30.063$, $p<0.05$. Appendix E shows the details of the one-way ANCOVA and a pair wise comparison that we ran to compare the experimental group and the control group over two semesters.

Tables 9.10 and 9.11 show that there is an epistemological change in the opposite direction for both control and experimental groups regarding the ‘justification for knowing’ factor over a period of two semesters. A One-way ANCOVA was conducted to determine a statistically significant difference between the experimental group and the control group on the post-test controlling for the pre-test over this period. The combination of reflective writing and labatorials has a significant effect on the post-scores of the epistemological test after controlling the pre-test scores, $F = 4.384$, $p<0.05$. Therefore, the difference between experimental and control groups is significant which means the epistemological change of ‘justification for knowing’ factor in the opposite direction for the experimental group is less than the epistemological change that the control group experienced in the opposite direction. The details of the analysis are presented in appendix E.

As can be seen in Tables 9.10 and 9.11, there is an epistemological change in both control group and experimental group regarding the ‘source of knowledge: authority’ factor. A One-way ANCOVA was conducted to determine a statistically significant difference between the experimental group and the control group on the post-test controlling for the pre-test. The combination of reflective writing and labatorials doesn't have a significant effect on the post-scores of the epistemological test after controlling the pre-test scores, $F = 1.307$, $p>0.05$. This means that both groups experienced an epistemological change regarding the source of knowledge factor over a period of two semesters and the combination of reflective writing and labatorials had no effect on this factor.

As can be seen in Tables 9.10 and 9.11, there is no epistemological change in both control and experimental groups regarding the 'attainability of truth' factor. Therefore, the combination of labatorial and reflective writing activity had no effect on this factor over a period of two semesters.

A One-way ANCOVA was conducted to determine a statistically significant difference between the experimental group and the control group on the post-test controlling for the pre-test. The combination of reflective writing and labatorials doesn't have a significant effect on the post-scores of the epistemological test after controlling the pre-test scores, $F = 1.906$, $p>0.05$ and there is no significant difference between the experimental group and the control group over a period of two semesters. The details of the statistical analysis are presented in appendix E. I also compared the post-scores of epistemological survey in fall 2014 and the post-scores of epistemological survey in winter 2015. Table 9.12 shows the comparison between the post-scores of the experimental group in fall 2014 and the post-test of the experimental group in winter 2015. Table 9.13 represents the comparison between the post-scores of the control group in fall 2014 and the post-test of the control in winter 2015.

Factors	Mean Post-test Fall	Mean Post-test Winter	N	Paired Differences (“Pre-test” – “Post-test”)			t	Sig. (2-tailed)
				Mean	Std. Deviation	Std. Error Mean		
Certainty/simplicity	3.40	3.27	63	0.129	0.412	0.0518	2.49	0.016
Justification: personal	1.91	1.87	64	0.0391	0.394	0.0492	0.793	0.431
Source: authority	3.29	3.38	63	-0.0952	0.521	0.0656	-1.452	0.152
Attainability of truth	4.07	4.10	63	-0.0317	0.581	0.0732	-0.434	0.666

Table 9.12 The results of paired t-test for the experimental group at the end of the winter semester 2015 compared to the end of the fall semester 2014 (Pre-test).

Factors	Mean Post-test Fall	Mean Post-test Winter	N	Paired Differences (“Pre-test” – “Post-test”)			t	Sig. (2-tailed)
				Mean	Std. Deviation	Std. Error Mean		
Certainty/simplicity	3.59	3.59	52	0.000	0.354	0.0490	0.00	1.000
Justification: personal	1.90	1.73	52	0.173	0.552	0.0766	2.26	0.028
Source: authority	3.38	3.31	52	0.673	0.582	0.0807	0.834	0.408
Attainability of truth	4.00	3.81	51	0.186	0.591	0.0828	2.25	0.029

Table 9.13 The results of paired t-test for the control group at the end of the winter semester 2015 compared to the end of the fall semester 2014

As can be seen in Tables 9.12 and 9.13, there is an epistemological change in the ‘certainty and simplicity of knowledge’ factor for the experimental group, while the control group experienced no change. I ran a One-way ANCOVA to compare the experimental group and the control for the ‘certainty and simplicity of knowledge’ and found that the difference is significant (Appendix E). This means that students’ beliefs about certainty and simplicity of knowledge kept changing in the winter semester and the combination of reflective writing and labatorials influenced the students' beliefs about certainty and simplicity of knowledge in two semesters. Table 9.12 shows that the experimental group did not experience any change in the 'justification for knowing,' 'source of knowledge: authority,' and 'attainability of truth' factors. As can be seen in Table 9.13, there is an epistemological change in the 'justification for knowing' factor in opposite direction. This shows that while the experimental group didn't experience any change in the opposite direction over the second semester, the 'justification of knowing' factor kept changing in the opposite direction for the control group. The results of a One-way ANCOVA analysis show that the difference between the experimental group and the control group for the 'Justification of Knowledge' factor is not significant (Appendix E).

There is no change in the 'source of knowledge: authority' factor for both experimental group and control group. I compared the experimental group and the control group by running a One-way ANCOVA analysis and did not find any significant difference between them (Appendix E). Regarding the 'attainability of truth' factor, the experimental group did not experience any change. The 'Attainability of truth' factor changed for the control group. The results of the One-way ANCOVA analysis showed that the difference between the experimental group and the control group is significant (Appendix E). Attainability of truth factor is related to the teachers' epistemological beliefs. Teacher's epistemological beliefs affect students' beliefs about the attainability of truth. For example, if a teacher applies a procedure to arrive at a single correct solution, makes students believe that truth is attainable by the experts. Conversely, a teacher who believes that knowledge is contextual and develops a range of alternate solutions to problems makes students believe that truth is contextual (King & Kitchener, 1994).

We also compared the results in the sections taught by myself and those in the other sections. Tables 9.14, 9.15, 9.16, and 9.17 show the results of the paired t-test analysis for the sections taught by myself and the ones taught by another lab instructor. The results are consistent with the results gained in Sections 9.1, 9.2, 9.3, and 9.4. Table 9.18 contains the results for the test of homogeneity of variance. The high significance values are good because they mean we do have homogeneity of variance. We also ran a One-way ANCOVA analysis to see whether there is any difference between the groups (both experimental and control) taught by myself and the groups (both experimental and control) taught by another lab instructor. The results show that there is no significant difference between the groups (Appendix F).

Our results provide a strong indication that a combination of an activity that gets students to examine textual material metacognitively with labatorials can produce statistically significant epistemological change, in particular in the 'certainty and simplicity of knowledge' and 'justification of knowledge' factors. These gains are measurably stronger than those observed in the control groups in both fall and winter semesters. Further discussions of the results gained are discussed in Chapter 10. We hope that our results would stimulate an effort by others to examine our hypothesis in other research settings.

Factors	Mean Pre-test	Mean Post-test	N	Paired Differences (“Pre-test” – “Post-test”)			t	Sig. (2-tailed)
				Mean	Std. Deviation	Std. Error Mean		
Certainty/simplicity	3.83	3.38	58	0.448	0.286	0.0375	11.94	0.000
Justification: personal	2.21	1.97	58	0.241	0.411	0.0540	4.475	0.000
Source: authority	3.88	3.37	58	0.513	0.627	0.0824	6.23	0.000
Attainability of truth	4.16	4.15	58	0.017	0.530	0.0695	0.248	0.805

Table 9.14 The results of paired t-test for the experimental group taught by the author (MS)

Factors	Mean Pre-test	Mean Post-test	N	Paired Differences (“Pre-test” – “Post-test”)			t	Sig. (2-tailed)
				Mean	Std. Deviation	Std. Error Mean		
Certainty/simplicity	3.69	3.27	52	0.421	0.364	0.0505	8.34	0.000
Justification: personal	2.13	1.95	52	0.183	0.357	0.0496	3.69	0.001
Source: authority	3.88	3.27	52	0.606	0.565	0.0784	97.73	0.000
Attainability of truth	3.87	3.86	52	0.00960	0.757	0.1050	0.092	0.927

Table 9.15 The results of paired t-test for the experimental group taught by other lab instructor

Factors	Mean Pre-test	Mean Post-test	N	Paired Differences (“Pre-test” – “Post-test”)			t	Sig. (2-tailed)
				Mean	Std. Deviation	Std. Error Mean		
Certainty/simplicity	3.89	3.64	60	0.244	0.318	0.0410	5.95	0.000
Justification: personal	2.28	1.82	60	0.458	0.691	0.0892	5.14	0.000
Source: authority	3.85	3.52	60	0.325	0.695	0.0898	3.620	0.001
Attainability of truth	3.89	3.98	60	-0.0917	0.794	0.1026	-0.894	0.375

Table 9.16 The results of paired t-test for the control group taught by the author (MS)

Factors	Mean Pre-test	Mean Post-test	N	Paired Differences (“Pre-test” – “Post-test”)			t	Sig. (2-tailed)
				Mean	Std. Deviation	Std. Error Mean		
Certainty/simplicity	3.71	3.53	42	0.182	0.380	0.0586	3.10	0.004
Justification: personal	2.43	1.85	42	0.583	0.818	0.1263	4.62	0.000
Source: authority	3.98	3.27	42	0.702	0.635	0.0980	7.17	0.000
Attainability of truth	3.87	3.80	42	0.0714	0.793	0.1224	0.584	0.563

Table 9.17 The results of paired t-test for the control group taught by other lab instructor

Factors	N	Certainty/simplicity	Justification: personal	Source: authority	Attainability of truth
Significance Value Experimental Groups	110	0.157	0.907	0.669	0.122
Significance Value Control Groups	102	0.259	0.216	0.624	0.861

Table 9.18 the results for the test of homogeneity of variance between the groups taught by the author (MS) and the groups taught by another lab instructor

Chapter 10: Conclusion and Future Directions

There are a small number of published studies on writing-to-learn in physics. Among the studies in this field, a common recommendation is that writing be included in classes because the authors believe that it will be beneficial to students. In the majority of these studies, the authors' claims about writing in physics are not backed up by qualitative and quantitative data and they do not help us know whether writing actually helps learning, or, if it does help, how it helps and what we need to do to make it an effective learning activity (Section 1.5.2). In order to answer these questions we collected qualitative and quantitative data to find out how reflective writing is helpful at achieving effective learning outcomes. We also evaluated the effect of using reflective writing, in combination with labatorials, on students' perspectives on knowledge and learning. Labatorials have been used at the University of Calgary and MRU for six years without conducting any study to improve them. In this project we studied students' perspectives on labatorials to explore how labatorials are helpful. This project begins to address such important questions about writing in physics education and also helps us improve physics labatorials in Mount Royal University based on students' perspectives and the quantitative data collected. In Chapter 1 (Section 1.5.1) we discussed that many researchers believed that there are few studies done to explore what different kinds of learning result from different kinds of writing experiences (Demaree, 2006; Gary Schumacher and Jane Nash, 1991; Langer, 1986). In this project we analysed the learning outcomes of using reflective writing in introductory physics labatorials in MRU.

This thesis establishes three main items:

1. Interviewees' perspectives on the specific aspects that make reflective writing successful at achieving effective student learning outcomes.

2. The characteristics of labatorials that are beneficial to students according to the interviews conducted and the characteristics of labatorials that we need to change to improve them.

3. The way most first year students perceived knowledge and learning and the influence of the combination of reflective writing and labatorials on students' epistemology. The third item helps us modify our lectures and laboratories in introductory physics courses to encourage a more expert-like way of thinking in introductory science courses.

10.1 Results of Our Studies

The first part of our research project focused on students' perspectives on reflective writing activities and how reflective writing can be a successful learning activity. We interviewed seven students who completed reflective writing assignments. We also assessed the interviewees' reflective writing products and the writing assignments of 41 students. Based on the interviews, we found the specific aspects that make reflective writing a successful learning activity and classified these aspects into three broad categories. First, reflective writing provides an opportunity for students to approach science in the manner of hermeneutics. Reflective writing expands students' possibilities of using pre-understanding and helps them expand their horizons. Second, reflective writing affects students' learning skills by improving students' understanding of concepts, problem solving skills, engagement and performance in the lab. Third, the emotional effects of reflective writing include motivation to read the textbook and lowering students' anxiety.

By evaluating students' reflective writing products we found that when the topics contained a lot of equations and formulas or the concepts were more abstract, students' writing was not as clear, understandable, or well organized and correspondingly the writing products were not usually in the reflective writing style. In general, writing became clearer and more understandable by the end of semester. The last five writing assignments (Assignments 5, 6, 7, 8, and 9) also contained the interpretation of equations, diagrams and figures presented in the textbook. The quality of writing and the style of writing heavily depend on the topic. This is not a surprising result. Kirkpatrick (Kirkpatrick and Pittendrigh, 1984) and Kalman (2006) also believe that understanding the physics is the most difficult part of writing and when the topic is more abstract it is more difficult for students to write down their ideas on paper. As we discussed in Chapter 1 (Section 1.5.2.1), Mullin (1989) mentioned the number of ways in which the "Writing in Physics" course has helped their students without providing any quantitative or qualitative proof of the actual effectiveness. He believed that "the content and style of their technical writing has improved" (p. 342) and his claim is consistent with what we gained based on analysis of the students' reflective writing products. Mullin also claimed that their students wrote with more confidence by the end of the semester. This is also consistent with what our interviewees mentioned about reflective writing activity. They believed that reflective writing improved their self confidence by the end of the semester and I presented this theme in the "emotional effects of reflective writing" category in Chapter 7. The analysis of the reflective writing products also revealed that there are more writing assignments written in first person by the end of the semester that implies more confidence. In Chapter 1 (Section 1.5.2.3), we reviewed the writing activities that Kirkpatrick conducted in his classrooms with the presence of an English teacher (Kirkpatrick & Pittendrigh, 1984). Kirkpatrick observed that even if many of his students were initially reluctant to write, their attitudes toward writing improved by the end of the semester. His observation is consistent with our results in this project. He also analyzed his students' writing products and concluded that his students' writing assignments improved significantly and their answers became more comprehensive and less disconnected by the end of the semester. He also observed more logical relationships among various concepts and believed that his students' essays became easier to read by the end of the semester. Although he believed that the presence of an English teacher in his classroom had a significant effect on achieving these learning outcomes, his claims are consistent with our results of the writing product analysis presented in this project in Chapter 6. Based on the comments left by his students, Kirkpatrick concluded that the most difficult part of writing was understanding the physics and once students understood the physics it was easier to write down their ideas on the paper. This is consistent with the analysis of reflective writing assignments presented in Chapter 6.

Kalman (2009) conducted a case study in 2008 to find out whether or not reflective writing is helpful and also focused on the strategies that students take to prepare their writing assignments. He improved the reflective writing instructions based on the insight of the five students who participated in his study. I have used the same instructions at MRU and in this project I did not find any new perception to change the existing instructions on reflective writing. Kalman (2009) focused on three topics in the interviews: "What do you view as the purpose of reflective writing?" and "How useful would you say the activity is?" and then "What procedures do you use to carry out reflective writing?" Kalman concluded that reflective writing provided teaching-learning opportunities for building strategies to improve the quality of thinking about physics phenomena. This conclusion is very broad and doesn't provide any detail explaining the strategies that improve the quality of thinking. To extend Kalman's studies on reflective writing we explored the details explaining how reflective writing is helpful and the reasons why it improves students' learning skills. In this study we classified the themes gained into three broad categories. The main category that emphasizes the effect of reflective writing on learning skills is consistent with what Kalman found in 2008. We found more details about the effect of reflective writing on learning skills and explained each theme in Chapter 7. The other main categories that we presented in this study (the hermeneutical approach and the emotional effects) reinforce the idea that reflective writing is a tool that helps students. We were also able to discuss the reasons why reflective writing is a helpful learning activity.

The second part of this project focused on students' perspectives on labatorials and both the positive and negative aspects of this activity. One of the most important goals for labatorials in MRU was to create a student-centered environment to help students examine their views, become familiar with other perspectives, and construct their own understanding of physics concepts. We have achieved this goal by using labatorials in introductory physics courses. During the labatorials we observed many discussions inside and between groups, which met our expectation for encouraging student participation. Another objective was to improve student satisfaction, hence, facilitate a positive learning environment. Based on interviews and anonymous comments made by students, there was an overall increase in student satisfaction due to instant feedback and one-on-one discussions with peers and the instructor. We classified the points mentioned by interviewees explaining the reasons why labatorials are helpful into two broad categories. First, the influence of labatorials on learning skills and second, the emotional influence of labatorials on students. Regarding the effect of labatorials on learning skills, we found that labatorials value students' pre-understanding and integrate it with the experiments through thinking, comparison, reasoning, and explaining. They help students explore the relationship among various physics concepts and improve students' engagement. Labatorials also improved students' understanding of the concepts. The emotional effects of labatorials on students involve lowering students' anxiety and improving self-confidence. The friendly lab environment has encouraged student communication and the instant feedback provided has increased student satisfaction. Reducing instructors' marking load is also a prominent achievement of the proposed lab method, which addresses the problem of not having enough time to mark the lab reports and give early feedback to students. We are aware of the challenges of the checkpoint system in labatorials discussed in Chapter 8. This issue has been identified, one unsuccessful approach (writing method at each checkpoint) was attempted and abandoned when it proved ineffective, and work continues to improve this issue.

In Chapter 1 (Section 1.5.1), we talked about the studies that support the need for active engagement to improve learning (Hake, 1998; Connally, 1989; Kalman, 2008). In this project we found that both reflective writing and labatorials improve students' engagement and this is one of the characteristics of these activities that make them successful at achieving effective student learning outcomes. Figure 10.1 shows the themes gained explaining why reflective writing and labatorials are successful learning activities. As can be seen in Figure 10.1, there are some common themes explaining how reflective writing and labatorials are helpful. Both activities improve students' understanding of the concepts and help students explore the relationship among various physics concepts. Both activities involve reasoning, thinking, comparison and explaining. In labatorials, we ask students to make predictions before doing the experiments. Interviewees appreciated the fact that labatorials value students' pre-knowledge and engage their pre-understanding with the experiments and the new materials presented. Similarly, in reflective writing students are asked to compare their pre-knowledge with the textbook. By looking at the common themes I conclude that reflective writing and labatorials encourage student to rely on their own reasoning and construct their own understanding of knowledge. My conclusion is consistent with the quantitative results that show a change in students epistemological beliefs in the ‘certainty and simplicity of knowledge’ dimension.

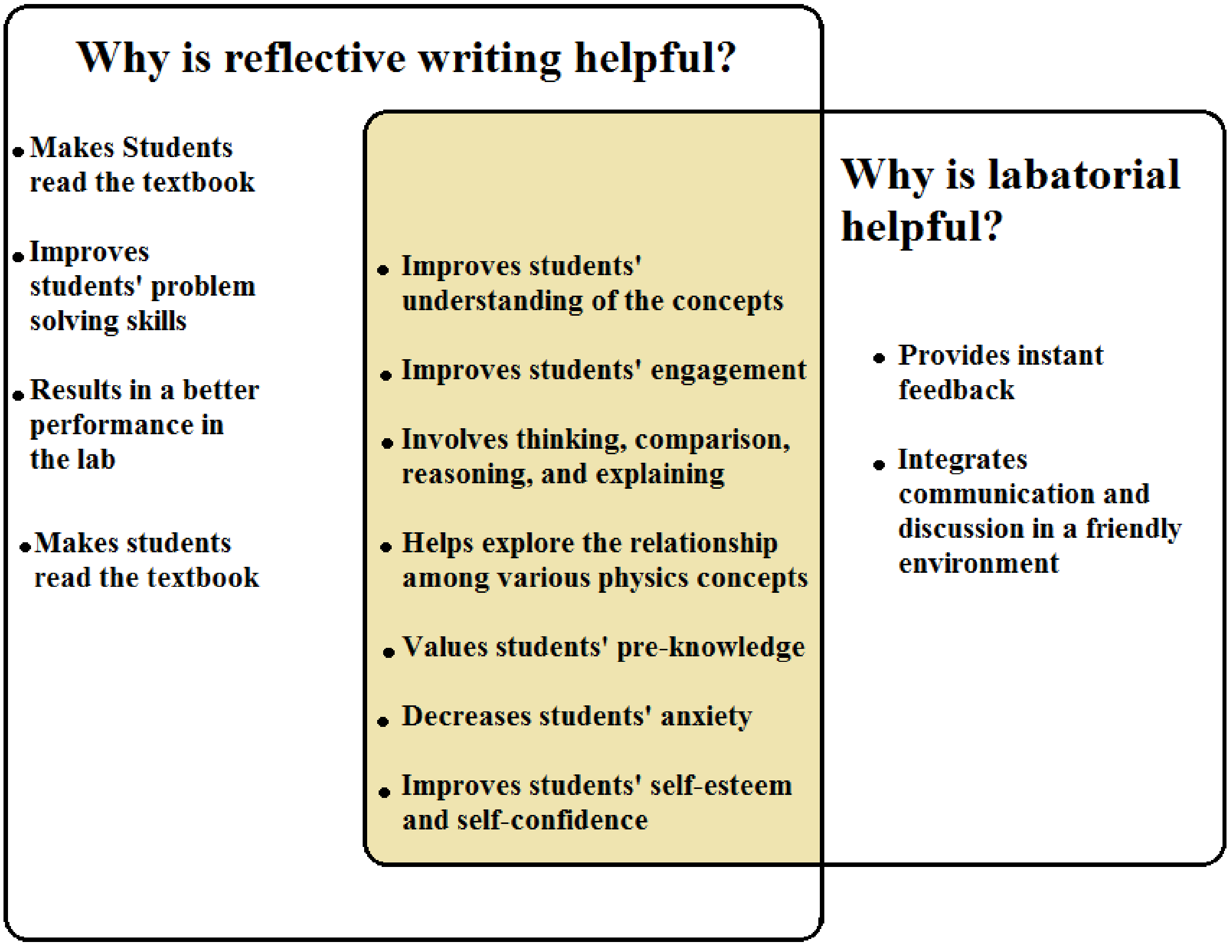


Figure 10.1: The themes gained explaining why reflective writing and labatorials are successful learning activities.

The third part of this project presented a quantitative study to evaluate any possible effect that the combination of reflective writing and labatorials might have on students’ beliefs about knowledge and learning. Madsen et al. (2014) pointed out that “in typical physics classes, students’ beliefs deteriorate or at best stay the same. There are a few types of interventions, including an explicit focus on model-building and/or developing expert-like beliefs that lead to significant improvements in beliefs" (p. 1). In traditional lecture courses as well as courses that use interactive engagement and lead to large gains on the Force Concept Inventory (Hestenes et al., 1992) and other content surveys, students' scores on the Maryland Physics Expectations Survey (Redish et al., 1998) at the end of the course are less expert-like than they were at the beginning. These courses usually have large enrolments, and are calculus-based (Madsen et al., 2014). The normal alternative to a lecture-based classroom format is a single type of intervention. We have been interested in seeing if an activity that gets students to examine textual material metacognitively (Reflective Writing) combined with one or more interactive interventions could help students change their approach to learning. Dr. Kalman's group found that using reflective writing activity as the only activity in the introductory physics courses had no effect on the students' epistemological beliefs during the semester (Huang & Kalman, 2012). They combined reflective writing with conceptual conflict collaborative groups followed by an argumentative essay and developed experimental and control groups to study students' epistemological beliefs at the beginning and end of the course. The results gained indicated that students who experienced the combination of reflective writing with conceptual conflict collaborative groups and argumentative essays became more expert-like after the one-semester intervention, beginning to see physics knowledge as interconnected and evolving, which can be better learned by relating the material to their prior knowledge and their life experience. Kalman concluded that to get an epistemological change we need to have more than one type of intervention and considered this as a strong hypothesis that should be tested more broadly. In this spirit we investigated the effects of the combination of reflective writing and labatorials on first year students enrolled in Phys1201 course at MRU. Results in the factor of simplicity/certainty showed that novice science learners become more expert-like after the one-semester intervention, beginning to see physics knowledge as interconnected and evolving, which can be better learned by relating to their prior knowledge and their life experience.

Labatorials ask students to make predictions and this values their pre-knowledge and their opinion. This makes them feel that their opinions are important and labatorials will integrate their beliefs and knowledge with the experimental results gained. Students need to compare their predictions with the experimental results gained and discuss whether or not the results support their predictions. This process involves thinking, comparison, reasoning, and explanation. As discussed in Chapter 8, the “prediction process” of labatorials encouraged students to use their pre-understanding to anticipate the experimental outcome and explain whether or not the experimental results support their predictions. The prediction activity motivated doubt, humility, and strength dispositions that we discussed in Section 1.6. The development of such dispositions encouraged a hermeneutical approach to science and helps students move towards having a more expert-like epistemology about certainty of knowledge. The prediction activity of labatorials along with reflective writing assignments helped students use their pre-understanding and moved them towards a more expert-like way of thinking about certainty of knowledge. Similarly, both activities (reflective writing and labatorials) encouraged students to think about the relationship among various physics concepts and helped have a more expert-like epistemology towards the simplicity of knowledge. The values of the effect size calculated for each factor (Appendix F), show that the most significant change happened for the ‘certainty and simplicity of knowledge’ factor. For this factor, students made further changes to a more expert-like epistemology during the second semester (please see the statistical results presented in Chapter 9).

There is an epistemological change in the opposite direction for both the control and experimental groups regarding the 'justification for knowing' factor, although the epistemological change of the 'justification for knowing' factor for the experimental group is less than the epistemological change that the control group experienced.

In Section 9.6 we saw that the experimental group did not experience any change in the 'justification for knowing' during the second academic semester, while the control group experienced an epistemological change in the 'justification for knowing' factor in the opposite direction. Justification is primarily concerned with the role of experiments and the use of data to support arguments. An epistemological change in the opposite direction for this dimension was not surprising. Based on my experiences in introductory physics labs, many students try to use the experimental results to prove what they see in the textbook or what they learned in the classroom. Based on my observation in the lab, I believe that students who provided reflective writing assignments before labatorials, showed a better performance in analyzing data and making comparison between their predictions and the data gained. On the other hand, students who provided summary writing assignments were reluctant to rely on their predictions and showed more tendencies to set aside their own opinions and accept the information suggested by the experimental data. My observation is consistent with the quantitative data gained. As we saw in Section 9.6, the experimental group did not experience any change in the 'justification for knowing' factor during the second semester, while this factor kept changing in opposite direction for the control group. The result of the 'justification of knowledge' factor is of great importance since I believe that as a lab instructor it is up to me to help students see experiments as a way of developing physics knowledge. One strong point of this study is that the epistemological results help us improve our lectures and physics laboratories to help students rely on experiments and analysis of experimental results to gain knowledge instead of proving what is presented in the textbook and lectures.

Although there is an epistemological change for both experimental and control groups regarding the ‘source of knowledge: authority’ factor towards a more expert-like way of thinking, there is no significant difference between these two groups. This shows that the combination of reflective writing and labatorials had no influence on this factor during the semester. The statistical results did not suggest any epistemological change in the ‘attainability of truth’ factor. The further analysis of ‘attainability of truth’ factor can be a part of our future studies since this factor is related to the teachers' epistemological beliefs. Teacher’s epistemological beliefs affect students’ beliefs about the attainability of truth. For example, if a teacher applies a procedure to arrive at a single correct solution, makes students believe that truth is attainable by the experts. Conversely, a teacher who believes that knowledge is contextual and develops a range of alternate solutions to problems makes students believe that truth is contextual (King & Kitchener, 1994).

The results of the epistemological analysis showed that the combination of reflective writing and labatorials can change students’ epistemological results during the semester. By comparing my results with the epistemological studies done by Kalman’s group I conclude that an activity that has students examine textual material metacognitively with one or more interactive interventions can produce epistemological change. We conclude that instructional interventions, where developmental changes are brought about over short periods of time, may provide important avenues to examine the process of epistemic change and its affective dimension. Further, such gains have been observed across a range of institutions, student learning environments, and relevant pedagogical tools. We hope that our results will encourage an effort to examine our hypothesis in other research settings.

Huang and Kalman (2012) conducted a multiple case study in two science courses in which students engaged in reflective writing. They explore relationships between students' performance in their writing products and students' epistemology and way of learning. Students enrolled in a calculus-based mechanics course were asked to complete reflective writing assignments on each chapter of the course textbook. Similarly, students enrolled in an introductory algebra-based course were provided with the same instructions for doing reflective writing assignments. Students enrolled in both courses completed an epistemological survey (a Likert scale questionnaire) developed by Huang and Kalman. The epistemological questions developed by Huang and Kalman are related to the 'certain/simple knowledge' factor of the questionnaire that we used in this study. Huang and Kalman interviewed six students and analyzed the quantitative scores on the survey as well as students' writing products. Based on only six cases, they found that students with higher scores on an epistemology survey tended to use reflective writing in a more effective way to enhance their learning of textual material. Kalman (2012) believed that if students approach the textbook in the manner of hermeneutics, they will consider their pre-understanding and if they find a conflict between their pre-understanding and the textbook, they will go back and forth between the two horizons to solve the conflict instead of ignoring their own preconceptions. Huang and Kalman (2012) observed a hermeneutical approach in the writing products of the students with higher survey scores. As discussed in Chapter 6, in this study we found that having a hermeneutical approach depends on the topic of the writing assignments. However, I looked at the scores of the students who gave me permission to go through their survey scores and their writing products in their consent forms to find any triangulation with Huang and Kalman's study in 2009 and 2010. As discussed in Chapter 9, the epistemological scores of students who had the lowest number of writing assignments with reflective writing style, indicate a more novice-like way of thinking.

10.2 The Trustworthiness of Qualitative Research

The trustworthiness of qualitative research generally is questioned by the researchers in the field of natural science and the ones who believe that subjectivity and objectivity must be separated in a research work to provide reliable results (Flyvbjerg, 2001). However, people like Gadamer and Heidegger believed that subjectivity is a part of a research work and it is not possible to separate the researchers' ideas from the events under study. A researcher is a part of the research work and having different interpretation of an event motivates other researchers to study the same phenomenon in an attempt to learn more the phenomenon or confirm the results of the other researchers or even find different results (Howell, 2012; Packer, 2010). My opinion about the trustworthiness of the qualitative research is close to Gadamer, Heidegger, and Flyvbjerg. However, I will present some criteria that positivist investigators (Shenton, 2004) consider in pursuit of a trustworthy study. I will explain how each criterion was considered in this thesis:

10.2.1 The adoption of research methodology. In a qualitative research, it is important to study the procedures of data collection and data analysis in the other comparable research works to incorporate "correct operational measures for the concepts being studied" (Yin, 2013). In this thesis we conducted a pilot study in fall 2013 and spring 2014 to make sure that the data collection and analysis procedures employed can address the main research questions. I also studied the research work done in the field of ‘writing in physics’ before the adoption of research methodologies.

10.2.2 The development of an early familiarity with the culture of participating. Establishing a relationship of trust between the interviewer and the interviewees is of great importance in a qualitative research work (Howell, 2012; Packer, 2010). Regarding the research ethical issue, I was not allowed to interview the students enrolled in my class. The instructor who interviewed the author’s students was familiar with MRU and worked in the Department of Chemistry and Physics. He visited the labs and interviewed students on the campus. He read the research ethical forms and was provided with detailed information about reflective writing, labatorials and Phys1201 course outline.

10.2.3 Random sampling of individuals to serve as informants. Although most qualitative research works involve purposive sampling, a random sampling approach may reduce the researcher’s bias in the selection of participants. Regarding the research ethical issues, the interviewees volunteered to participate in this research work. However, a random sampling approach was employed in the quantitative part of this research and 7 lab sections were randomly selected to complete summary writing products, while the other eight sections were asked to complete reflective writing assignments during the semester.

10.2.4 Triangulation. Triangulation may involve using more than one method to collect data on the same topic. Triangulation is a way of assuring the trustworthiness of a research work through the use of a range of methods to collect data on the same topic, which involves different types of sample as well as methods of collecting data. Triangulation can also be used to capture different dimensions of the same phenomenon. In this research work we interviewed 7 students and we also evaluated their reflective writing products to see whether their statements were consistent with what they did during the semester. The reflective writing products of 41 other students were also assessed to triangulate with and improve our understanding of the results.

10.2.5 Tactics to help ensure honesty in information. Each participant in the study should be given the opportunity to refuse to participate in the study so as to ensure that the data collected involves those who are willing to take part and express their ideas. In our research work, interviewees volunteered to participate in this project and had right to withdraw from the study at any point. Similarly, students who gave me permission to use their reflective writing products and epistemological survey results had the right to withdraw from the study.

10.2.6 Frequent debriefing sessions and peer scrutiny of the research project. Frequent debriefing sessions between the researcher and his or her supervisors may widen the vision of the investigator. Such sessions encourage discussing alternative approaches and may draw attention to the flaws in the data collection and analysis procedures. I had weekly meeting with my supervisors and Dr. Kalman's research group to discuss data collection, developing ideas, interpretations and data analysis. I also discussed the data analysis procedure, specially the statistical methods that I used in this project with my colleagues who had expertise in these fields. Dr. Ganesh Bhandari who is a statistics professor in MRU, and Dr. Ahmed Ibrahim who is a member of Dr. Kalman's research group helped me with choosing the right statistical methodologies to analyze the epistemological survey data.

10.2.7 Examination of previous research findings. This criterion helps you to find out the degree to which the project's results agree with those of past studies. In Section10.1, I compared the results of this study with those of the studies done previously in the field of writing in physics.

Many researchers believed that the findings of a qualitative study are specific to a small number of participants and so it is impossible to demonstrate that the findings and conclusions are applicable to other situations and participants (Creswell, 2002; Merriam, 1988; Shenton, 2004; Yin, 2013). However, there are other researchers like Flyvbjerg (2001) who believe that it is incorrect to conclude that one cannot generalize the results of a qualitative research work. Flyvbjerg (2001) believed that the generalization of the conclusions depend on the samples chosen and the methodology taken to conduct the research. For example, the rejection of Aristotle's law of gravity was not based on a large random sample of trials of objects falling from a wide range of randomly selected heights. It was a single experiment that involved the clever choice of samples (metal and feather).

10.3 Future Directions

This project helped us find out what topics students struggle with in Classical Physics 1. Based on the writing products we found that projectile motion, circular motion and momentum are the topics that are more abstract and less sensible. I need to modify the labatorials related to these topics to make sure that they clarify the difficult topics that students struggle with. I will also talk to the course instructors to discuss other possible activities that we can implement to help students gain a better understanding of these topics.

Since we found that there is a change in students' epistemological beliefs in the opposite direction regarding the 'justification for knowing' factor, I plan to explore the reasons for such negative change. More research in this field can help us improve labatorials and reflective writing activities in introductory physics courses.

We followed an integrated model of epistemological analysis in this project. Cognitive models study students' reasoning processes when they encounter a problem. Since solving problems is a part of learning physics, I aim to collaborate with some cognitive psychologists to study possible changes that the combination of labatorials and reflective writing might have on students' reasoning processes when they solve physics problems in the future.

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Appendix A: Reflective Writing Rubric

	Points **Features present in the reflective writing product**	**3** **Meets criteria fully**	**2** **Meets most of the criteria**	**1** **Minimally meets the criteria**	**0** **Does not meet the criteria at all**
1	A fluent piece of work in the student's own words	Thoughts flow in a mostly logical manner, self talk is present to monitor thinking	Thoughts flow in an associative manner, shows some self talk	The student is not thinking about their own thoughts but is mostly paraphrases of material presented in the textbook or your lectures	The piece is a summary; it is essay writing, directly copied from a text book
2	Student explains key concepts in his or her own words	Student has constructed his/her own understanding of the concepts and has used his/her own reasoning to make sense of the concepts	Students has used his/her own reasoning to make sense of the concepts, but some key concepts are missing	Concept written in a manner that is largely a rewrite of "textbook" version. Illustrates selection of a concepts with little consideration of its meaning	Rewrite of a textbook definition
3	Student relates recently introduced key concepts to previously studied concepts within the course	Sets out clear understanding of how the concept follows from or is related to concepts previously studied in the course. Student is able to use the same principle to explain various phenomena.	Partial understanding of how the concept follows from or is related to concepts previously studied in the course	Mention of previously studied concepts without any explanation of how they relate to concepts under study in current sections	No relationships to previously studied concepts are given.
4	Student relates key concepts to his/her own life experiences	Shows clear understanding of how the concepts occur in everyday situations	Shows partial understanding of how the concepts occur in everyday situations	Mention of everyday situations without any explanation of how they relate to concepts under study in current sections	No relationships to his/her own life experiences are given
5	Student identifies that the ideas/facts/data (if applicable) presented in the textbook are in conflict with the students' own ideas	Clearly sets out how the student's own ideas about concepts difer from the versions found in the textbooks	Sees that there is a conflict between the students' own ideas and versions found in textbooks without clearly setting out the difference	Notes a difference between the students' own ideas and the versions found in the textbooks without any explanation	No conflicts identified Student's reflective writing product contains some conflicts that students has not realized and addressed.
6	If there is any conflict identified, student discusses the conflict between the ideas/facts/data	Student sets out a discussion of the difference between the students' own ideas and the versions found in the textbooks trying to fully understand the difference	Student attempts to discuss the difference between the students' own ideas and the versions found in the textbooks	Student notes the difference between the students' own ideas and the versions found in the textbooks without any discussion	No discussion
7	In addition to identifying a conflict, Student formulates his/her own question(s).	Student realizes that there are concepts in the textbook that s/he does not understand and elaborates a clear question.	Student sets out a question that is not clearly formulated	The question formulated does not address the conflict between the students' own ideas and the versions found in the textbooks.	No questions given
8	Student attempts to address his/her own meaningful questions	Student attempts to answer questions arising (point 7) in a lengthy clear discussion using his/her own reasoning	Student makes an attempt to answer questions arising (point 7) in a short clear discussion without using his/hr own reasoning.	Student attempts to answer questions arising (point 7) in a rambling unclear discussion	No attempt to answer a question

Appendix B: A Sample of Labatorial Activity

MOUNT ROYAL UNIVERSITY
Department of Chemistry and Physics
PHYS 1201
Circular Motion

Preparation: Read Physics: Second Custom Edition for Mount Royal University, section 3.8, 6.1, 6.2, and 6.3.
Equipment: Force sensor, Photo-gate, metallic cylinder, long string, Phet Simulation

Learning goals: Explore Circular motion

Question 1:
A Ladybug is crawling in a circle around a flower like in the picture below.

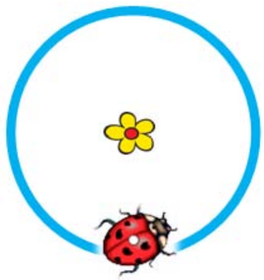


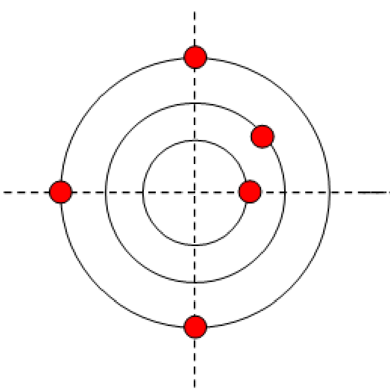
Figure 1. Lady bug crawling in a circle around a flower

a. Sketch what you think the velocity and acceleration vectors would look like on Figure 1.

b. Use ***Ladybug Motion 2D Simulation*** (ladybug-motion-2d_en.jar) to check your ideas. Startup the simulation and choose circular motion. Make corrections if necessary

Question 2:
Suppose the bug is on a rotating plate.

a. Draw what you think the **velocity** and **acceleration** vectors would look like at the locations shown in Figure 2 and 3. Indicate the higher velocity and acceleration with longer arrows.



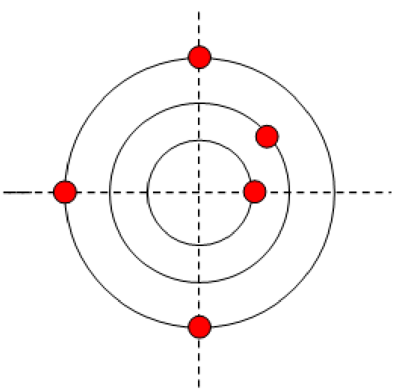


Figure 2. Velocity vectors (Expectations)   Figure 3. Acceleration vectors (Expectations)

a. Use the **Ladybug Revolution** simulation (rotation_en.jar) to check your ideas and make corrections on Figure 4 and 5. Start the simulation by clicking on the plate and spinning it.

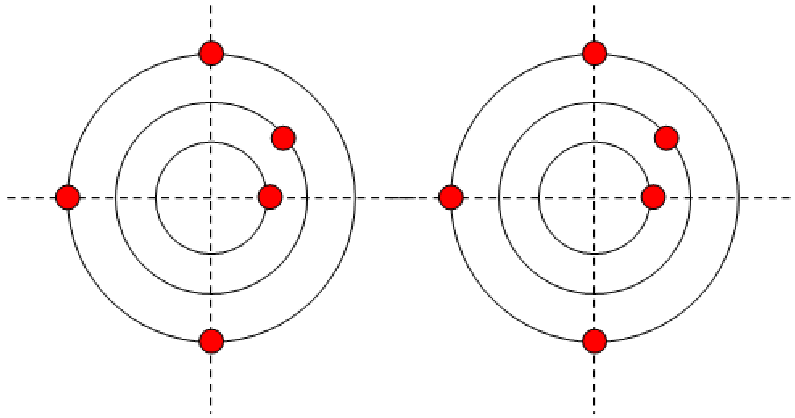
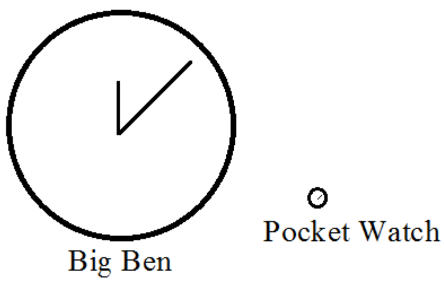


Figure 4. Velocity vectors   Figure 5. Acceleration vectors

Question 3:
A pocket watch and Big Ben are both keeping perfect time.

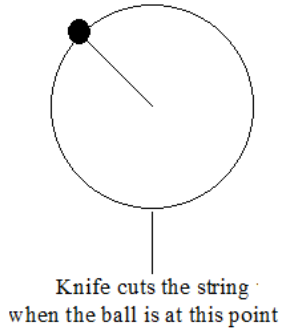


a. Which minute hand has the larger angular velocity ω (change in angle per time)? Why?

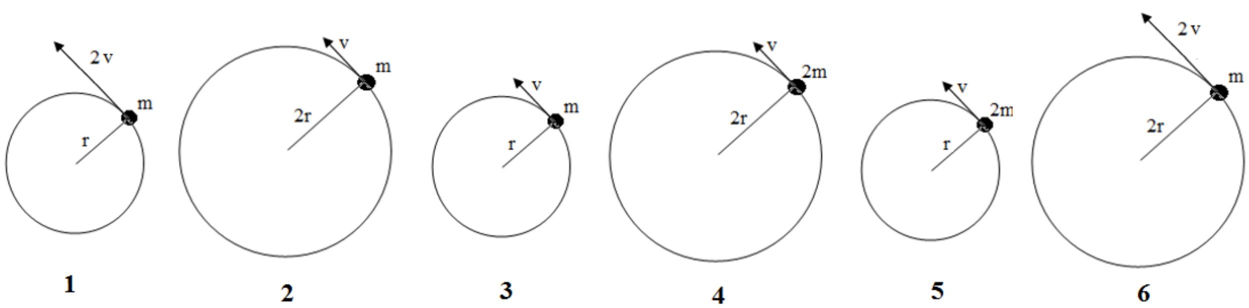
b. Which minute hand's tip has the larger velocity (tangential velocity)? Why?

Checkpoint 1: before moving on the next part, have your instructor check the results you obtained so far.

Question 4:
A ball swings in a vertical circle on a string counter clockwise. During one revolution, a very sharp knife is used to cut the string at the instant when the ball is at its lowest point. Sketch the subsequent trajectory of the ball until it hits the ground.



Question 5:
The following figures show particles moving in horizontal circles on a table top. Rank in order, from largest to smallest, the string tension and explain why.



Checkpoint 2: before moving on the next part, have your instructor check the results you obtained so far.

Question 6:
In this part of the experiment we will have a cylinder hanging from a string tied to a force sensor (figure 6). The cylinder will move like a pendulum. There is a photo-gate which measures the velocity of the cylinder at the lowest point of the swing.

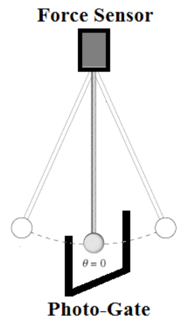


Figure 6. Object hanging from a string, has a periodic motion.

a. Draw a free body diagram for the hanging cylinder when it is not moving.

b. If the cylinder was moving what would the free body diagram look like at the lowest point?

c. Make sure photo-gate is directly below the hanging cylinder. Connect the photo-gate to Data Studio. Verify that the “Velocity In Gate, Ch1” is selected. Use calipers to measure the diameter of the cylinder. Select the “Constants” tab and enter the measured diameter of the cylinder as the “Flag Length”.

d. Connect the force sensor to port “A”. On DataStudio click on “A” and add the “force sensor” (not the “force sensor [student]” option). Change the sample rate to 50.

e. Remove the pendulum from the force sensor and hit “start” and drag “Run #1” under the force sensor to “Digits”. When there is nothing attached to the force sensor it should read zero. To set the reading zero, press the “TARE” button on the force sensor. When the force sensor shows zero, stop recording data by hitting “Stop”.

f. For this part of the experiment, re-attach the pendulum. Start the cylinder swinging and hit the “Start” button on DataStudio. Record about 10 seconds of data. Drag your velocity and force data into a single graph. Bring up the smart tool on each graph. Choose seven velocity data and note the force at those data points and record in Table 1.

g. Measure the length of the pendulum from pivot point of the pendulum to the center of the cylinder.

h. What type of force does the force sensor measure in this experiment?

i. Calculate the centripetal force for each velocity and record your data in Table 1. Show a sample calculation below.

Table 1. Measured, calculated, and experiment data

	Length of the Pendulum (m)	Mass of the Cylinder (kg)	Velocity of the cylinder (m/s)	Force (force sensor) (N)	Calculated centripetal Force (N)
Point #1					
Point #2					
Point #3					
Point #4					
Point #5					
Point #6					
Point #7					

j. How does the centripetal force you have calculated compare with the force that the force sensor has measured.

k. Try to come up with the possible explanation if your calculated values are far from your experimental results. Call your lab instructor.

l. If you want to repeat the experiment again, what could you do to get better results?

Final Checkpoint: Please clean your area and have your instructor check your work before leaving lab.

Activity	**Explanations**	**Points**	**Mark**
Worksheet	If you finish all checkpoints, you will get 50%.	5	
Group work	• All students must be engaged in labatorial activity. • Students need to assign roles to each group member. • An interactive and practical discussion between group members is mandatory. • Interaction with other groups and lab instructor • If any student is not working in group or the answers to the questions are different from what the other members of the group have answered, she/he will not get this 15%.	1	
Individual work	• This shows the student's engagement to the lab activity and how well the student has done the role assigned to him/her. • All students must work, discuss and share their information in the lab. • All appropriate data collected • Data are well organized and neatly displayed, including graphs • The results of calculations are presented with appropriate units. • Understands the sequential nature of the procedure and the purpose of each stage. • Suggestions for improvement of lab (e.g. procedure and data quality/quantity) • Logic and reasoning is evident in efforts to relate results to prediction / hypothesis / theory. • Related physics concepts are stated correctly.	1	
posttest	After checking the last checkpoint with your lab instructor, you will do a posttest exercise. You are supposed to finish the posttest within 5 minutes.	1	
Reflective writing activity (if the mark is available)	Please check the course outline.	2	

If a group leaves without cleaning the table, all the members will lose 1 mark.
If a student does not have a printed worksheet, she/he will lose 1 mark.
Food, drink and cell phones are not allowed in the lab, if seen you will lose 1 mark.
If you are more than 5 minutes late, you will lose 1 mark. You cannot perform the lab if you are more than 10 minutes late.

Final Mark out of 10:

Appendix C: Discipline-Focused Epistemological Beliefs Questionnaire

DISCIPLINE-OCUSED EPISTEMOLOGICAL BELIEFS QUESTIONNAIRE

PHYSICS

Instructions: Please answer the following questions as best you can on scale **1** to **5**, with 1 being **strongly disagree** and 5 being **strongly agree**. We are interested how students think about different subjects. When you are answering these questions, please ive us your beliefs about the field of

PHYSICS

1	2	3	4	5
strongly disagree				strongly agree

1. Truth is unchanging in this subject. 1 2 3 4 5

2. In this subject, most work has only one right answer 1 2 3 4 5

3. Sometimes you just have to accept answers from the experts in this field, even if you don't understand them. 1 2 3 4 5

4. What we accept as knowledge in this field is based on objective reality. 1 2 3 4 5

5. All professors in this field would probably come up with the same answers to questions in this field. 1 2 3 4 5

6. The most important part of work in this subject is coming up with original ideas. 1 2 3 4 5

7. If you read something in a textbook for this subject, you can be sure it is true.

1 2 3 4 5

8. A theory in this field is accepted as true and correct if experts reach consensus.

1 2 3 4 5

9. Most of what is true in this subject is already known. 1 2 3 4 5

10. Ideas in this subject are really complex. 1 2 3 4 5

11. In this subject, it is good to question the ideas presented. 1 2 3 4 5

12. Correct answers in this field are more a matter o opinion than fact.

1 2 3 4 5

13. I scholars try hard enough, they can find the answers to almost anything.

1 2 3 4 5

14. The most important part o being an expert in this field is accumulating a lot of facts.

1 2 3 4 5

15. I know the answers to questions in this field because I have figured them out for myself.

1 2 3 4 5

16. One expert's opinion in this field is as good as another's. 1 2 3 4 5

17. Experts in this field can ultimately get to the truth. 1 2 3 4 5

18. Principles in this field are unchanging. 1 2 3 4 5

19. Principles in thid field can be applied in any situation. 1 2 3 4 5

20. If my personal experience conflicts with ideas in the textbook, the book is probably right.
1 2 3 4 5

21. There is really no way to determine whether someone has the right answer in this field.
1 2 3 4 5

22. Expertise in this field consists of seeing the interrelationships among ideas.
1 2 3 4 5

23. Answers to questions in this field change as experts gather more information.
1 2 3 4 5

24. All experts in this field understand the field in the same way.
1 2 3 4 5

25. I am more likely to accept the ideas o someone with first-hand experience than the ideas of researchers in this field. 1 2 3 4 5

26. I am most confident that I know something when I know what the experts think.

1 2 3 4 5

27. First-hand experience is the best way of knowing something in this field.

1 2 3 4 5

Appendix D: Interview Questions

Pre-interview

Q1. How do you study for the course PHY1201?

Probe: You told me that you use … to study for this course. What other materials do you use in studying for this course?

Probe: Do you use your own reasoning, past experiences, what the teachers say, what you read in books?

Q2. Before the next question, let me first give you the definition of pre-understanding. You may already have some ideas about physical concepts, such as force, velocity, mass and so on. These ideas may come from your former educational experience, or from your experience of the real world. Let's call all those ideas in your mind before you entered this course your pre-understanding. How do you think this pre-understanding helps you?

Probe: Do you bring your pre-understanding into studying for this course?

Q3. What was your understanding of the relationship between force and motion before entering the course PHYS 1201 (pre-understanding)?

Probe: Did your pre-understanding help you understand the relationship between force and motion? How?

Q4. How do you think the role of this pre-understanding helped you in your study?

Q5. What do you expect out of the course?

Probe: Does reflective writing activity help you meet your expectations of the Phys 1201 course? How (in which way)?

Probe: Do you find labatorials helpful for you when studying for this course? Why?

Probe: Does labatorial activity help you meet your expectations of the Phys 1201 course? How (in which way)?

Probe: Do you find reflective writing activity helpful for you when studying for this course? Why?

Q6. What do you expect out of the labatorials?

Probe: Does the reflective writing activity help you meet your expectations of labatorials? How (in which way)?

Q7. How do you work on each labatorial worksheet in the lab?

Q8. How do you do your reflective writing activity?

Q9. Did you find reflective writing helpful for you when studying for this course? Why?

Probe: How helpful is reflective writing for you in the lab?

Q10. Did you find labatorials helpful for you when studying for this course? Why?

Q11. If the answer to Q2 is yes, how does reflective writing help you use your pre-understanding?

Probe: How does reflective writing help you to engage in your studying process?

Q12. If the answer to Q2 is yes, how does the labatorial activity help you to use your pre-understanding?

Probe: How does labatorial activity help you to engage in your studying process?

Q13. Do you think that physics knowledge can change? How?

Post-interview, winter 2014

Q1. How do you study for the course Phys 1201?

Probe: So you told me that you use … to study for this course. What other materials do you use in studying for this course?

Probe: How do you get physics knowledge? What do you rely on for getting knowledge?

Probe: Do you use your own reasoning, past experiences, what the teachers say, what you read in books?

Q2. Are your ideas about learning physics different now, compared to before you took this course?

Probe: What experiences in this course had helped you shape your ideas about learning physics? How did these things influence you?

Q3. What exactly did you do at the beginning of this course to promote your learning of the content?

And what exactly did you do in the middle of this course to promote your learning of the content?

What exactly did you do at the end of this course to promote your learning of the content?

Q4. Before the next question, let me first give you a definition of pre-understanding. You may already have some ideas about physical concepts, such as force, velocity, mass and so on. These ideas may come from your former educational experience, or from your experience of the life world. Let's call all those ideas in your mind before you entered this course your pre-understanding. What do you feel were the concepts contained in your pre-understanding?

Probe: Would you define your understanding of pre-understanding? What do you consider as your pre-understanding?

Probe: Did you bring your pre-understanding into studying for this course?

Q5. How did you use this pre-understanding in this course?

Probe: What if what you read (or what teacher says) is not consistent with your pre-understanding? What do you do in this case?

Probe: In what way does your pre-understanding help you in studying for this course? (or if it does not help you can you explain why?)

Probe: Have the concepts in your pre-understanding been changed by taking this course?

Q6. What was your understanding of the relationship between force and motion before entering the course PHYS1201?

Probe: Did your pre-understanding help you understand the relationship between force and motion? How?

Q7. What is your understanding of the relationship between force and motion now?

Probe: What activities help you shape your present ideas about the relationship between force and motion?

Q8. How did you go from your pre-understanding to your present ideas about the relationship between force and motion?

Q9. Based on the procedure you just described, how does reflective writing help you in examining your ideas?

Probe: What about labatorials? Did they help you to engage into the procedure? How?

Q10. In our pre-interview you told me about your expectations of this course. Did the Phys 1201 course meet your expectations?

Probe: How do you feel about the course right now?

Probe: Did reflective writing activity help you meet your expectations of the Phys 1201 course?

How?

Q11. You also told me about your expectations of labatorials in our pre-interview. Did Phys 1201 labatorials meet your expectations?

Probe: What did you get out of labatorials?

Probe: Did the reflective writing activity help you meet your expectations of labatorials? Would you explain how?

Q12. How did you do your reflective writing activity?

Probe: Did you change your procedure of doing reflective writing during the semester? Why? What did you change?

Q13. Did you find reflective writing helpful for you when studying for this course?

Q14. Did you find labatorials helpful for you when studying for this course?

Q15. Do you think that physics knowledge can change? How?

Appendix E: Epistemological analysis of students over two semesters

Tests of Between-Subjects Effects

Dependent Variable: CERT post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	14.627[a]	2	7.314	60.358	.000	.519
Intercept	.398	1	.398	3.288	.072	.029
CERTpre	11.806	1	11.806	97.431	.000	.465
Group	**3.643**	**1**	**3.643**	**30.063**	**.000**	**.212**
Error	13.571	112	.121			
Total	1368.672	115				
Corrected Total	28.199	114				

Table E.1: The results of the one-way ANCOVA test for the 'certainty/simplicity of knowledge' factor over a period of two semesters

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1.0	2.0	-.358*	.065	.000	-.488	-.229

Table E.2: A pair wise comparison doesn't show any significant difference between the experimental group and the control group over two semesters for the 'certainty/simplicity of knowledge' factor

Tests of Between-Subjects Effects

Dependent Variable: JUST Post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	4.910[a]	2	2.455	9.102	.000	.139
Intercept	7.297	1	7.297	27.054	.000	.193
JUSTPre	4.376	1	4.376	16.224	.000	.126
Group	**1.182**	**1**	**1.182**	**4.384**	**.039**	**.037**
Error	30.476	113	.270			
Total	413.750	116				
Corrected Total	35.386	115				

Table E.3: The results of the one-way ANCOVA test for the 'Justification for knowing' factor over a period of two semesters

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1.0	2.0	.206*	.098	.039	.011	.401

Table E4: A pair wise comparison doesn't show any significant difference between the experimental group and the control group over two semesters for the 'justification for knowing' factor

Tests of Between-Subjects Effects

Dependent Variable: AUTH post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	7.434[a]	2	3.717	16.717	.000	.230
Intercept	4.685	1	4.685	21.069	.000	.158
AUTHPre	7.281	1	7.281	32.747	.000	.226
Group	**.291**	**1**	**.291**	**1.307**	**.255**	**.012**
Error	24.903	112	.222			
Total	1321.250	115				
Corrected Total	32.337	114				

Table E.5: The results of the one-way ANCOVA test for the ‘source of knowledge: authority’ factor over a period of two semesters

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1.0	2.0	.101	.088	.255	-.074	.276

Table W.6: A pair wise comparison doesn’t show any significant difference between the experimental group and the control group over two semesters for the ‘source of knowledge: authority’ factor

Tests of Between-Subjects Effects

Dependent Variable: ATTN post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	9.247[a]	2	4.623	14.591	.000	.208
Intercept	12.538	1	12.538	39.567	.000	.263
ATTNpre	6.886	1	6.886	21.729	.000	.164
Group	**.604**	**1**	**.604**	**1.906**	**.170**	**.017**
Error	35.174	111	.317			
Total	1844.500	114				
Corrected Total	44.421	113				

Table E.7: The results of the one-way ANCOVA test for the 'attainability of truth' factor over a period of two semesters

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1.0	2.0	.152	.110	.170	-.066	.370

Table E.8: A pair wise comparison doesn't show any significant difference between the experimental group and the control group over two semesters for the 'attainability of truth' factor

Tests of Between-Subjects Effects

Dependent Variable: CERT Winter post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	13.104[a]	2	6.552	48.614	.000	.465
Intercept	1.540	1	1.540	11.424	.001	.093
CERTFallPost	10.282	1	10.282	76.293	.000	.405
Group	.916	1	.916	6.796	.010	.057
Error	15.095	112	.135			
Total	1368.672	115				
Corrected Total	28.199	114				

Table E.9: The results of the one-way ANCOVA test for the 'certainty/simplicity of knowledge' factor in winter 2015. The comparison is made based on the post-scores in fall 2014 and the post-scores in winter 2015

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1.0	2.0	-.184*	.070	.010	-.323	-.044

Table E.10: A pair wise comparison between the experimental group and the control group for the 'Certainty/Simplicity of Knowledge' factor in winter 2015. The comparison is made based on the post-scores in fall 2014 and the post-scores in winter 2015

Tests of Between-Subjects Effects

Dependent Variable: JUST Post Winter

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	14.327[a]	2	7.164	38.439	.000	.405
Intercept	2.829	1	2.829	15.180	.000	.118
JUSTPostFall	13.793	1	13.793	74.014	.000	.396
Group	**.522**	**1**	**.522**	**2.800**	**.097**	**.024**
Error	21.059	113	.186			
Total	413.750	116				
Corrected Total	35.386	115				

Table E.11: The results of the one-way ANCOVA test for the 'justiication for knowing' factor in winter 2015. The comparison is made based on the post-scores in fall 2014 and the post-scores in winter 2015

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.0	2.0	.135	.081	.097	-.025	.295

Table E.12: A pair wise comparison between the experimental group and the control group for the 'justification for knowing' factor in winter 2015. The comparison is made based on the post-scores in fall 2014 and the post-scores in winter 2015

Tests of Between-Subjects Effects

Dependent Variable: AUTH post Winter

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	9.962[a]	2	4.981	24.931	.000	.308
Intercept	11.491	1	11.491	57.518	.000	.339
AUTHPostFall	9.809	1	9.809	49.097	.000	.305
Group	**.381**	**1**	**.381**	**1.907**	**.170**	**.017**
Error	22.375	112	.200			
Total	1321.250	115				
Corrected Total	32.337	114				

Table E.13: The results of the one-way ANCOVA test for the 'source of knowledge: authority' factor in winter 2015. The comparison is made based on the post-scores in fall 2014 and the post-scores in winter 2015

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.0	2.0	.116	.084	.170	-.050	.282

Table E.14: A pair wise comparison between the experimental group and the control group for the 'source of knowledge: authority' factor in winter 2015. The comparison is made based on the post-scores in fall 2014 and the post-scores in winter 2015

Tests of Between-Subjects Effects

Dependent Variable: ATTN Post Winter

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	15.240[a]	2	7.620	28.986	.000	.343
Intercept	8.283	1	8.283	31.507	.000	.221
ATTNPostFall	12.879	1	12.879	48.991	.000	.306
Group	1.767	1	1.767	6.720	.011	.057
Error	29.181	111	.263			
Total	1844.500	114				
Corrected Total	44.421	113				

Table E.15: The results of the one-way ANCOVA test for the 'attainability of truth' factor in winter 2015. The comparison is made based on the post-scores in fall 2014 and the post-scores in winter 2015

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
					Lower Bound	Upper Bound
1.0	2.0	.251*	.097	.011	.059	.442

Table E.16: A pair wise comparison between the experimental group and the control group for the 'attainability of truth' factor in winter 2015. The comparison is made based on the post-scores in fall 2014 and the post-scores in winter 2015

Appendix F: Author's sections and other lab instructor's section

Tests of Between-Subjects Effects

Dependent Variable: CERT post cont

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	3.931[a]	2	1.965	25.068	.000	.336
Intercept	3.224	1	3.224	41.120	.000	.293
CERTprecont	3.622	1	3.622	46.190	.000	.318
Group	**.018**	**1**	**.018**	**.228**	**.634**	**.002**
Error	7.762	99	.078			
Total	1330.375	102				
Corrected Total	11.693	101				

Table F.1: The results of the one-way ANCOVA test for the 'certainty/simplicity of knowledge' factor comparing the control group taught by the author and the control group taught by another lab instructor

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.0	2.0	.028	.058	.634	-.087	.142

Table F.2: A pair wise comparison between the control group taught by the author and the control group taught by another lab instructor for the 'attainability of truth' factor

Tests of Between-Subjects Effects

Dependent Variable: CERT post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	14.420[a]	2	7.210	68.120	.000	.560
Intercept	.032	1	.032	.299	.586	.003
CERTpre	14.075	1	14.075	132.978	.000	.554
Group	**.008**	**1**	**.008**	**.078**	**.781**	**.001**
Error	11.325	107	.106			
Total	1244.359	110				
Corrected Total	25.746	109				

Table F.3: The results of the one-way ANCOVA test for the 'certainty/simplicity of knowledge' factor comparing the experimental group taught by the author and the experimental group taught by another lab instructor

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.0	2.0	-.018	.063	.781	-.143	.108
2.0	1.0	.018	.063	.781	-.108	.143

Table F.4: A pair wise comparison between the experimental group taught by the author and the experimental group taught by another lab instructor for the 'certainty/simplicity of knowledge' factor

Tests of Between-Subjects Effects

Dependent Variable: JUST post cont

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.067[a]	2	.034	.099	.906	.002
Intercept	12.327	1	12.327	36.100	.000	.267
JUSTPrecont	.047	1	.047	.138	.711	.001
Group	**.011**	**1**	**.011**	**.033**	**.855**	**.000**
Error	33.805	99	.341			
Total	374.875	102				
Corrected Total	33.873	101				

F.5: The results of the one-way ANCOVA test for the 'justification for knowing' factor comparing the control group taught by the author and the control group taught by another lab instructor

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.0	2.0	-.022	.119	.855	-.258	.214

Table F.6: A pair wise comparison between the control group taught by the author and the control group taught by another lab instructor for the 'justification for knowing' factor

Tests of Between-Subjects Effects

Dependent Variable: JUST Post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	16.533[a]	2	8.266	71.767	.000	.573
Intercept	1.738	1	1.738	15.085	.000	.124
JUSTPre	16.523	1	16.523	143.453	.000	.573
Group	**.031**	**1**	**.031**	**.269**	**.605**	**.003**
Error	12.325	107	.115			
Total	450.063	110				
Corrected Total	28.857	109				

Table F.7: The results of the one-way ANCOVA test for the 'justification for knowing' factor comparing the experimental group taught by the author and the experimental group taught by another lab instructor

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.0	2.0	-.034	.065	.605	-.162	.095
2.0	1.0	.034	.065	.605	-.095	.162

Table F.9: A pair wise comparison between the experimental group taught by the author and the experimental group taught by another lab instructor for the 'justification for knowing' factor

Tests of Between-Subjects Effects

Dependent Variable: AUTH Post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.780[a]	2	.390	1.306	.275	.026
Intercept	11.843	1	11.843	39.663	.000	.286
AUTHPre	.118	1	.118	.395	.531	.004
Group	**.732**	**1**	**.732**	**2.451**	**.121**	**.024**
Error	29.561	99	.299			
Total	1246.813	102				
Corrected Total	30.341	101				

Table F.10: The results of the one-way ANCOVA test for the 'source of knowledge: authority' factor comparing the control group taught by the author and the control group taught by another lab instructor

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1.0	2.0	.174	.111	.121	-.047	.395
2.0	1.0	-.174	.111	.121	-.395	.047

Table F.11: A pair wise comparison between the control group taught by the author and the control group taught by another lab instructor for the 'source of knowledge: authority' factor

Tests of Between-Subjects Effects

Dependent Variable: AUTH post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	11.841[a]	2	5.921	21.956	.000	.291
Intercept	4.710	1	4.710	17.468	.000	.140
AUTHPre	11.585	1	11.585	42.963	.000	.286
Student	.246	1	.246	.911	.342	.008
Error	28.853	107	.270			
Total	1256.813	110				
Corrected Total	40.694	109				

Table F.12: The results of the one-way ANCOVA test for the ‘source of knowledge: authority’ factor comparing the experimental group taught by the author and the experimental group taught by another lab instructor

Pairwise Comparisons

(I) Student	(J) Student	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1.0	2.0	.095	.099	.342	-.102	.291

Table F.13: A pair wise comparison between the experimental group taught by the author and the experimental group taught by another lab instructor for the ‘source of knowledge: authority’ factor

Tests of Between-Subjects Effects

Dependent Variable: ATTN Post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	.861[a]	2	.431	1.272	.285	.025
Intercept	29.087	1	29.087	85.948	.000	.465
ATTNPre	.009	1	.009	.027	.870	.000
Group	**.848**	**1**	**.848**	**2.506**	**.117**	**.025**
Error	33.504	99	.338			
Total	1591.250	102				
Corrected Total	34.365	101				

Table F.14: The results of the one-way ANCOVA test for the ‘attainability of truth’ factor comparing the control group taught by the author and the control group taught by another lab instructor

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1.0	2.0	.185	.117	.117	-.047	.418

Table F.15: A pair wise comparison between the control group taught by the author and the control group taught by another lab instructor for the ‘attainability of truth’ factor

Tests of Between-Subjects Effects

Dependent Variable: ATTN post

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	14.483[a]	2	7.242	22.785	.000	.299
Intercept	10.782	1	10.782	33.926	.000	.241
ATTNpre	12.165	1	12.165	38.275	.000	.263
Group	**.500**	**1**	**.500**	**1.574**	**.212**	**.014**
Error	34.008	107	.318			
Total	1816.500	110				
Corrected Total	48.491	109				

Table F.16: The results of the one-way ANCOVA test for the 'attainability of truth' factor comparing the experimental group taught by the author and the experimental group taught by another lab instructor

Pairwise Comparisons

(I) Group	(J) Group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval for Difference	
					Lower Bound	Upper Bound
1.0	2.0	.139	.110	.212	-.080	.358

Table F.17: A pair wise comparison between the experimental group taught by the author and the experimental group taught by another lab instructor for the 'attainability of truth' factor

The Effect Size of Each Epistemological Factor in Fall 2014

Factor	Effect Size
Certainty/Simplicity of Knowledge	0.63
Justification of Knowledge	0.40
Source of Knowledge: Authority	0.11
Attainability of Truth	0.049

Table F18: The Effect Size of Each Epistemological factor in fall 2014

Factor	Effect Size
Certainty/Simplicity of Knowledge	1.098
Justification of Knowledge	0.43
Source of Knowledge: Authority	0.25
Attainability of Truth	0.052

Table F18: The Effect Size of Each Epistemological factor in two semesters

Factor	Effect Size
Certainty/Simplicity of Knowledge	0.36
Justification of Knowledge	0.24
Source of Knowledge: Authority	0.28
Attainability of Truth	0.27

Table F18: The Effect Size of Each Epistemological factor in winter semester