Helping Students to get a better Understanding of Physics Concepts using the Learning Tool 'Course Dossier Method'

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ABSTRACT

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Wahidun Nahar Khanam

The Course Dossier Method is a writing-to-learn tool based upon Gadamer's hermeneutical approach (Gadamer, 2004) and scaffolding using student reviewers based upon social constructivism (Vygotsky, 1978). This method is usually used for non-science students. The course PHYS 200 (From Particles to Galaxies) was offered for non-science students (without requiring any mathematical problems) in the winter semester 2014 at Concordia University. This method was also used in the regular physics course PHYS 456 (Classical Electrodynamics) in 1995.

In this method students used different kinds of writing activities (during the course): writing reflections (before class), 'Critiques' (after class) and final essay writing (Course Dossier with six entries) at the end of the course in lieu of the final exam for non-science students. For science students this method was used in conjunction with other activities. This research investigated in what way the 'Course Dossier Method' improves students' general understanding of concepts using writing different procedures and reviewers' comments.

Traditional learning techniques for the classroom is often ineffective in helping students grasp concepts. The purpose of this study is to help students learn in an active learning environment and promote their scientific thought into a higher level. Comparing students' earlier Critiques with later Critiques and also with students' Course Dossiers, we found that that students' general understanding of physics concepts improved.

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Introduction

When I applied for graduate studies in the physics department at Concordia University, Professor Dr. Calvin Kalman offered me the position of research assistant in physics education; I wondered what the purpose of educational research in Physics is! Then I searched the web sites to know about this kind of research and also to read some of Dr. Kalman's articles. It was really interesting and made me curious to know, what is the real learning or true learning needed for understanding the concepts of physics behind text or physical equations? Although I took my degree in a renowned university in our country at the department of physics and had the opportunity to sit in many scholarly professors' classroom, the traditional lecture-based or teacher centered learning method did not give me an appropriate way to think about the actual concepts behind physics. After learning about physics educational research and learning tools like reflective writing and the course dossier method I realized the difference between true learning and rote learning; and that motivated me to start my research in this area. It also reminded me that the lecture-based learning method forced us to memorize the rules or equations to solve the problems rather than discovering the concepts behind physics, because that method did not show us how to learn and how to think about physical phenomenon in depth. One of our instructors asked us to write or to have a group discussion with classmates about the course materials. Sometimes we did that and it had a very good impact on our learning. One of my friends received lower marks in her undergraduate physics courses because she was absolutely dependent on lecture notes and sometimes tried to memorize the rules to solve the problems. When she changed her learning strategies in her graduate level and had group discussions with other classmates it was

possible for her to get very good marks. Now she is a lecturer in physics in a government college, which is a very competitive job in our country. This kind of experience encouraged me to start my research in physics education. I wish to help students improve their conceptual understanding in a proper way and to provide them with a concrete learning environment.

Moreover, I took a course (Qualitative Research Course) at McGill in the Educational and Counselling Psychology department. In doing that course I experienced a clear idea about the difference between rote learning and true learning. The course was three hours per week. It included a free-writing part before entering the class (20% of total marks) every week, a group discussion section (20% of total marks) with my classmates, a midterm involving writing a book review(20% of total marks) and writing a final essay-overview of the course (40% of total marks). At the beginning of the course I was very anxious about the course because the course was really very different for me than the physics courses I had taken. So I was worried about how to manage the course to get a good credit. As the course was going on and consequently I realized what an amazing tool is "Writing-to-Learn". The free-writing before the class ensured that I would have an idea about what would be going on in the next class and made me think about the materials conceptually in every class. This writing also helped me to correct my misconceptions by myself. The group discussion part also had a very positive impact on our learning to understand the course materials in a clear manner. This discussion helped us to share our thoughts with each other and all together brought our perceptions to a higher level. As there was no final exam, we were free to think in writing the final essay

at home and had the chance to review everything over and over again. I have to say this type of course design ("Writing-to-Learn") helped me to get good marks in that course.

In science education and teaching it is a crucial problem for the students that they do not understand the scientific terms because the textbooks are written in a format that seems to students to come from a foreign culture (Kalman, 2011). In reading the science textbook the students misunderstand many concepts, because the student's interpretations of the textual content and the author's interpretations are different. The main issue in this concern is that the course design for a typical science classroom is not sufficient for the students' to overcome their misconceptions. Traditional learning methods or lecture-based learning methods are mostly teacher centered. In this method, the science courses, especially physics courses are designed for the students to solve some problems as home assignments. Questions are set for a midterm and for a final exam with similar problems. Therefore the students' minds are motivated by how to solve the problems without finding the basic concepts behind these problems. So they solely depend on lectures presented in the class or the equations or rules found in the textbook. Most of the time, the students memorize the rules to solve the problems needed for passing the exam without understanding the concepts behind them. Therefore, in a traditional course design, the students face problems to understand the actual meaning of the subject matter. This lack of understanding causes problems for students when they take upper level courses. For humanities students in taking a physics course for non-science students, this type of course design is even more problematic than for science students to understand the subject matter, because they don't have a background in physics. Humanities students are afraid of taking a physics course, because they think that a student has to understand

complex mathematics or equations to learn. Therefore a typical traditional classroom is threatening for humanities students. A proper learning tool can help the students; not only science students but also humanities students to understand the general concepts of physics. The writing-to-learn tool, course dossier method (Kalman, 2008) can help the students to learn physics concepts using certain writings procedures. The idea of the course dossier method is to use writing procedures based upon Gadamer's hermeneutical approach (Gadamer, 2004) and scaffolding using student reviewers based upon social constructivism (Vygotsky, 1978).

The course dossier method is usually used for non-science students. It has also been used in regular physics courses. Kalman (2008) has had successes in using this method in his courses (physics courses for humanities students and regular physics courses for physics students). The current study used the course dossier method in the courses PHYS 200 and PHYS 456.The course PHYS 200 (From Particles to Galaxies) was offered for non-science students in the winter semester 2014 and the course PHYS 456 (Classical Electrodynamics) is a regular physics course given in 1995 at Concordia University by Dr. Calvin S. Kalman. The students were not required to do any mathematical problems for the course PHYS 200. How did students understand this physics course without mathematics? The answer is 'writing to learn' methods. Writing-to-learn strategies have become increasingly valued in science teaching (Mullin, 1989; Rice, 1998 & McDermott, 2010). To get students to actively construct their new knowledge, the emphasis of writing tasks should be based more on reflection about their knowledge (Hand, Prain & Wallace 2002). "Writing can serve as a tool to improve the quality of teaching as well as to promote deeper and more meaningful student learning" (Larkin & Bundy, 2005, p. 1). In

the course dossier method, students used different kinds of writing activities (during the course): writing reflections (before students came to class), concept writing-'critiques' (after class) and final essay writing (course dossier with six entries) at the end of the course in lieu of the final exam. For the regular physics course PHYS 456, the course dossier was an additional part with other activities. The different types of writing procedures forced the students' to learn the actual concepts and get rid fear about physics.

The purpose of this study is to investigate in what way writing the critique is helpful to improve the students' understanding of the subject matter? In what way the reviewers' comments are useful for students in analyzing the subject matter? How helpful is the course dossier method to improve the students' general understanding of concepts behind physics? How has this method changed the students' views on physics? The following chapters of the thesis will answer these questions.

According to Eger (1992), Gadamer's version of hermeneutics is the appropriate framework in science education. Chapter 1 briefly describes the hermeneutical approach in science education. This chapter also describes the hermeneutical circle and students understanding of the scientific text. Moreover, Vygotsky's social constructivism and way of scaffolding of students thinking level is also briefly described in chapter 1.

Misconception is a common problem in science education. Eger (1992) argued that misconception or preconception plays a very important role in physics learning. We will explore how this works in Chapter 1. The course dossier method is designed so that students become aware of their preconceptions and can use the preconceptions in their writings and rewritings within the mechanism of the hermeneutical circle. Part of the course dossier method is that students who are not in the courses act as reviewers.

Reviewers' comments can help the students to promote their understanding about the course materials in the manner of Vygotsky (1978) social constructivism.

Several studies on the writing-to-learn strategy are reviewed in Chapter 2. A comparative view of traditional and non-traditional writing-to-learn methods and their advantages and disadvantages are also given in this chapter. Furthermore, the procedures of the course dossier method are briefly described here.

The methodology of the study is discussed in Chapter 3. Data analysis of each individual student, comparative analysis of different cases and; results and discussion are briefly described in this chapter.

Chapter 4 is the concluding chapter. In this chapter the overall findings from the investigation and advantages of course dossier method and its implementations are described.

Chapter 1

Theoretical Context

In science teaching, the crucial problem for the students is to understand the scientific concepts as the sentences in the textbook seem to the students to be a part of a foreign culture (Kalman, 2011).The practice of hermeneutics can help students overcome this problem. Moreover the students can construct their knowledge to a higher level with the aid of peers by means of Vygotsky's social constructivism point of view. The current chapter will discuss the theoretical perspectives of hermeneutics and social constructivism that fitted in the research. In section 1.1, I will present why Gadamer's version of hermeneutics is appropriate for science education. In Section 1.2, I will discuss how the hermeneutical circle can be used to understand the scientific meaning of text. The social constructivism framework is presented in section 1.3.

1.1 Hermeneutics in Science Education

Traditionally hermeneutics is the theory of interpretation of text. Originally it was used by biblical scholars to understand the bible. It was then adopted for human sciences to understand the life world as "life worlds created through and embedded in language" (Borda 2007, p. 1030). In many aspects Hans George Gadamer's philosophical hermeneutics (2004a) is an appropriate framework for science education (Eger, 1992). Eger explained that in social sciences the practitioners deal with the context of language relating to humans and society. In natural sciences on the other hand, scientists explain natural things in their own language (Eger 1992). Therefore construction of knowledge in both academic disciplines is inevitably related to language. The important thing is to

understand the meaning of the language in our life worlds (social or nature) in a proper way. Gadamer (2004) noticed that when someone tries to understand text he or she is actually projecting the meaning of the text as a whole that emerges from the initial meaning. This constant projection permits the reader to produce an understanding of the text. In every projection there exist some prejudices or misconceptions. These misconceptions are used to initiate the projection of new meanings to understand the text. Gadamer argued that prejudices or misconceptions cannot be overcome entirely until we open our mind in processing our knowledge to construct in a certain way (Borda, 2007). Gadamer's philosophical hermeneutics concern a way of being rather than a way of method to interpret the text. Gadamer thought this way of being permitted us to be aware of our limitation to challenge our misconceptions to understand the world. In his paper, Eger (1992) considers prejudices as misconceptions or preconceptions in our understanding process. Students come to science classes with misconceptions, because there is a gap between the students' understanding of the meaning of the contents and the author's understanding presented in the textbook. Bevilacqua and Giannetto (1995) highlighted this gap as misconceptions. Eger noticed that the misconception is strictly related to preconception and plays a very positive role in science education. Dealing with misconception is essential to hermeneutical practice (Bevilacqua & Giannetto, 1995). Construction of knowledge depends on our life experience that belongs to the hermeneutical practice of presupposition that is preconceptions. So preconceptions are strictly related to what already existed in our learning process i.e. our 'being' according to Heidegger (1962). The hermeneutical approach to the interpretation of text is used for corrections of misconceptions or preconceptions. The problem of meaning is another

issue in natural science. In educational research, "meaningful learning is central in the work on preconceptions, conceptual construction, conceptual nets and critical thinking" (Eger, 1992 p. 337). Meaningful learning depends on the whole of the text and the meaning of the whole text depends on the individual words (Eger, 1992). The mechanism of hermeneutical circle proposed by Gadamer (2004) is the key point in the learning process. Gadamer's version of the hermeneutical circle is to start with preconception or pre-understanding. Gadamer (1975, p. 269) defined the horizon as "the range of vision that includes everything that can be seen from a particular vantage point." A new horizon, that is, understanding or experience is created by the 'linguistic' fusion of the subject matter of the interpreter and object matter of the text within the hermeneutical event (Porter & Robinson, 2011). So for true understanding, the fusion of horizons is a very crucial "event of opening ourselves, our horizons, to others (other lives, questions, ideas)" (Porter & Robinson, 2011, p. 86). To acquire a horizon means that "one learns to look beyond what is close at hand-not in order to look away from it, but to see it better within a larger whole and in truer proportion" (Gadamer 1975, p. 272). When learners build up their horizon in reading the text, there may exist with some misconception in the understanding process. The two horizons (the horizon projected by the students and the horizon of text projected by the author) can overlap if and only if the learners are aware of their preconceptions. Consciousness of preconceptions allows the learners to understand the initial meaning of the parts of the text and the initial meaning of the parts allow them to project a new meaning and so on. Interpretation of the text is basically the back to forth movement that is, the hermeneutical circle. Students can enhance their conceptual understanding in bridging their own horizon with the text horizon as

Bevilacqua and Giannetto (1995, p. 4) argued that "a wider bridge than an extension is required." The extension can be achieved if the misconceptions are clarified and the differences of the life world (social) and the scientific world can be recognized. Moreover Bevilacqua and Giannetto argued that a reduction-realization process can overcome the misconceptions. From Bouchdahl's (1992) point of view the reduction-realization process is related to the hermeneutical phenomenon. Bevilacqua and Giannetto pointed out "in the reduction process it loses all the theoretical aspects that shape it, while in the realization process it acquires a new interpretation and thus new possibility of existence" (p. 10). This process allows the students' to interpret the scientific phenomenon in different possible ways, so that the student can be capable to get rid of misconceptions.

In his paper Borda (2007) argued certain hermeneutic dispositions are required in science education to gain true knowledge. Borda explained the term disposition as "one's disposition is consciously formed state or habit of mind" (p.1029).The disposition is the learners' sub- conscious mind particularly related to their thinking disposition and a way to approach to the subject matter (Ritchhart, 2001). Gadamer (1986) thought that awareness of preconceptions is important in education in order to gain understanding. Awareness of preconceptions helps to find the correct questions that expand one's life world through the movement of the hermeneutical circle (Gagamer, 1986). Also Gadamer argued that for the practice of hermeneutic consciousness we must be aware of our limitations. This means we have to be conscious of our misconceptions. So awareness of misconceptions helps us to expand our horizon to a truer position and to complete the hermeneutical circle. As I mentioned earlier the two horizons cannot overlap until the learners awaken their pre-understanding. Another hermeneutic disposition, openness of

mind (questions and answering) is crucial for science education. Gadamer (1986) believed that one must open his or her mind to gain the knowledge from other's view, but not losing one's own view. Openness of mind is the process of questioning and answering (Risser, 1997). This type of engagement of hermeneutic disposition helps the students to examine their preconceptions (Borda, 2007). Hence hermeneutic disposition of awareness and openness of mind uncover our preconceptions and preconceptions expand our horizon within the mechanism of the hermeneutical circle. The next section will discuss the way of understanding in the manner of a hermeneutical circle.

1.2 Hermeneutical Circle

The hermeneutical circle is the fusion of two horizons (the horizon of the learner and horizon of the text). Segraves (2004) argued that "the essence of the hermeneutical circle is the relationship between the whole and its parts. The parts cannot be understood in isolation from the whole, and the whole is understood by the coherence of the parts. Here whole means the horizon of the text. Interpretation moves in a circle between parts of the text and the whole text and between the whole text and parts of the text." Therefore the hermeneutical circle is going forward and backward movement to interpret the whole text and its parts. The hermeneutical circle enables students to fuse two horizons -the students' own horizon acquired by their own understanding of the text and/or their life experiences that is pre-understanding and the horizon of the textbook presented by the author. Ideally the hermeneutical circle will conclude when the two horizons overlap each other completely. "The process of fusion is continually going on, for their old and new continually grow together to make something of living value, without either being explicitly disguised from other" (Gadamer, 1975, p. 273). According to Eger (1992), the

interpretation of text is basically a state of motion in cognitive space. The motion occurs when the interaction between the horizons have some overlap.

Students come into science classes with their own perceptions and beliefs that comprise of their life experiences or of some former theoretical knowledge from text or a combination of both. Consider horizon 'A' of the student and horizon 'B', which is constructed by the author. When a student comes to a text, two horizons are in view: the horizon of the student (Horizon A) and the horizon of the text (Horizon B). One's horizon does not limit vision to what is nearby. A conceptual diagram is used here (Figure1) to schematize the process of the hermeneutical circle as follows:

Step 1: When students read the text they build their new horizon (A). This horizon is the combination of students' parts i.e. the students' pre-understanding, experience from their life world and experience from the text book. This is the students' whole. The text whole (horizon B) is a combination of its parts.

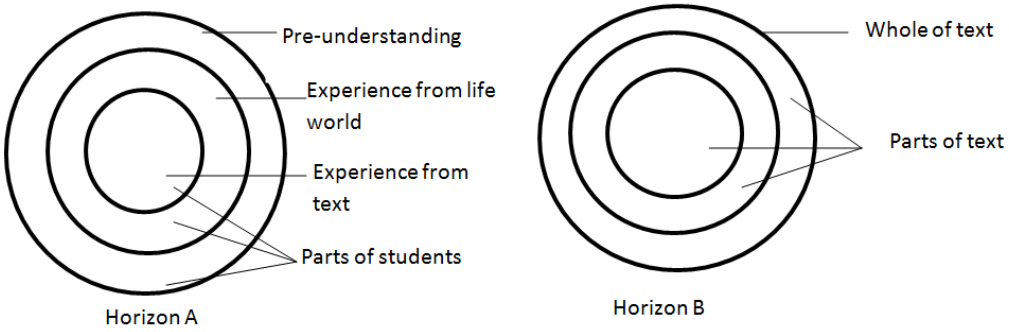

Fig.1 Horizon 'A' of Students and 'B' of Author's Horizon of the Textbook

Step 2: When students' are looking at a particular part of the textbook that they are trying to understand, they refer to their entire understanding. It is their understanding

from the viewpoint of this particular part of the textbook. The hermeneutical circle begins when two horizons overlap. In Fig. 2, part 'C' means that the student's understanding and the text's meaning overlap in this area. But the rest of horizon 'A' contains a mismatch of the students understanding of the meaning of the text. So they may try to correct their understanding. In this case, their horizon shifts in the direction of the horizon projected by the textbook. In reviewing the particular part again they may discover, more contradictions. This is the back-and-forth movement of the hermeneutical circle. As they go along and make corrections their horizon shifts in the direction of the horizon projected by the textbook.

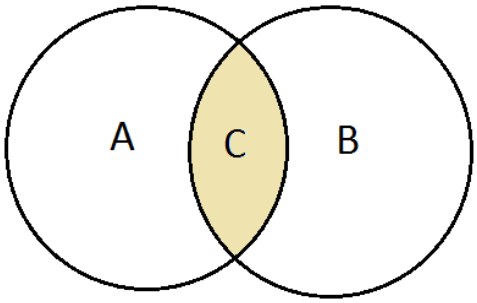

Fig. 2 Fusion after 1st Pass (Khanam & Sobhanzadeh, 2014)

Step 3: Students come back to the text and read it again to create a new horizon (A), and then harmonize again the two horizons. Look at part 'D' in Fig. 3- if this area is increased, it means that their horizon shifted to the horizon projected by the text. In every pass of the circle the students' horizon comes closer and closer to the horizon projected by the text.

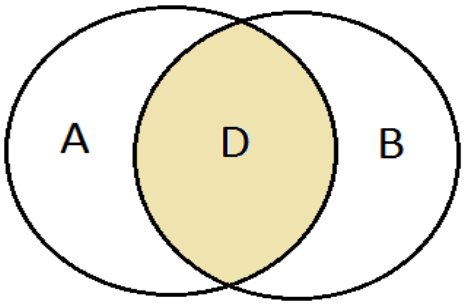

Fig. 3 Fusion after 2nd Pass (Khanam & Sobhanzadeh, 2014)

Students are truly making their own understanding of what the textbook says. Understanding is a process of fusion of the two horizons. This process encourages students to engage actively in their learning rather than being a passive accepter of the pre-existed meaning of the textbook.

A learning tool is required to enhance students' conceptual understanding in engaging science text within the manner of the hermeneutical circle. If students want to see the whole picture of the text it necessarily to set their learning tool to a certain focal point. Gadamer (2004) termed this focal point as the 'vantage point'. The course dossier method (Kalman, 2008) is such a tool that helps the students to engage with the hermeneutical circle and helps the students to expand their horizon to come closer to the horizon of the text. The next chapter will briefly describe in what way this method will be helpful for the students in understanding the subject matter by means of Gadamer's version of hermeneutical movement.

1.3 Social Constructivism

The idea of Vygotsky's (1978) social constructivism is that the students can construct their scientific knowledge with the assistance of other people. Vygotsky's (1978) notion

of ‘Socio-Cultural’ learning and teaching indicates that society is a key norm where students acquire knowledge in many ways- from classroom, family, friends or other social sources. Learning is a process that influences as-acted on by the environment (teacher, family, and friends). According to Vygotsky, learning is considered as an external process. In this process we internalize our individual thinking with others thinking (Wink & Putney, 2002). Moreover, Vygotsky believed that learning and development of thinking are an interrelated, dynamic process (Wink & Putney, 2002), because ‘learning is not development’ but properly organized learning causes mental development. Vygotsky viewed that thoughts and speech are the key factors that impact on experience. Students use language to explain their thoughts and use speech to share those thoughts with others that promotes the experience. For example when students read the text book about Newton’s law of motion they are thinking about the important concepts relating to motion like force, velocity or acceleration. When they share their concepts with their classmates or peers they reconstruct their knowledge as an active learner, because they are not solely depend on the instructor’s lectures. Thus an active learning environment is created through the socio-cultural context and the students become the active participants in the learning process. According to Vygotsky, the students who solve problems alone and the students who solve the problems with the help of another person, have differing intellectual developments .The difference of their intellectual development is defined by Vygotsky (1978) as the ‘zone of proximal development’ (ZPD): “the distance between the actual developmental level as determined by independent problem solving and the potential development as determined through problem solving ...in collaboration with...peers” (p. 88). Vygotsky’s framework of ZPD

teaches us that learners can develop their intellectual level to a higher level through the social interaction with others. Vygotsky viewed that learning is a variety of external developmental processes as mentioned earlier. When learners interact with people in their environment or cooperate with their peers, causes, they enhance the ZPD. Thus the students' can scaffold their intellectual knowledge to a higher level with the aid of other people like teachers or peers. As Wink and Putney (2002, p. 62) noted "we individually decide what is important to understand, and we actively reconstruct for ourselves the information we have taken up from interaction with others." From the social constructivist point of view the formation of knowledge is constructed not transmitted. In this knowledge construction processes the students can more easily examine their concepts when they interact with others than if they had to examine their concepts on their own. The integrations of students' existing concepts with the information taken up from others provide them with a higher level understanding of the concepts. In this thesis I examine in what way the course dossier method (reviewers' comments) helped the students to scaffold their knowledge in line with Vygotsky's social constructivism.

Chapter 2

Writing-to-Learn

The 'Writing-to-Learn' strategy helps students to improve their conceptual thinking. For science courses 'writing-to-learn' strategies can also help students in solving quantitative problems (Countryman, 1992; Kalman, 2001; Mayer & Hillman, 1996). "Writing can serve as a tool to improve the quality of teaching as well as to promote deeper and more meaningful student learning" (Larkin & Bundy, 2005, p. 1).Writing-to-learn activity is a process that students can use to generate and clarify their understanding of scientific concepts for themselves (McDermott, 2010).

Rivard's (1994) review of papers on 'writing to learn in science' revealed that in science education many educators accepted the writing-to-learn strategy in their classroom. Students became more aware about the subject matter through a proper writing -to-learn tool. Moreover, he argued that "the process of writing is important, not only for learning about something of acquiring knowledge, but for generating a personal response to something, for clarifying ideas, and for constructing knowledge" (p. 970). Mullin (1989) noticed that writing on topics in physics can help students to improve their writing skills. He believed that the students have been encouraged in heuristic thinking and learning through writing activities. Ellis's (2004) study on writing-to-learn activities showed that a writing strategy can help science students to engage with knowledge. It causes students to translate their thoughts into words, which in turn gets them to reflect on their understanding.

Summary writing is not part of such a writing-to-learn strategy. Summary writing cannot help the students to understand the concepts of science in depth. The idea of summary writing is that students just paraphrase the basic concepts through the viewpoint of the textbook author's words rather than their own words. In summary writing the students don't have the opportunity to explain the scientific terms explicitly. This type of writing cannot promote students actual thinking. McDermott and Hand (2010, p. 521) pointed out that "traditional writing genres generally hold that science as a discipline and worldview has developed a specific associated style of writing designed to accurately convey scientific ideas and connections among these ideas." The traditional style of writing encouraged the students to practice the similar text used by scientist, not to describe their scientific understanding by their own words (McDermott & Hand, 2010). On the other hand, non-traditional writing tasks help the students to connect emerging knowledge and the technical vocabulary of science of everyday language and their past experiences (Rowell, 1997). Therefore in non-traditional writing the students have the opportunity to explain the scientific terms in their own words and connect those ideas to their life world. For this reason, it has been shown that non-traditional writing enhances the students' learning of science content and thoroughly connects it to thinking.

It emerges from McDermott and Hand's (2010) research that, non-traditional writing tasks, which get the students to explain scientific words in everyday language, helps them to construct the new knowledge. They argued "writing was not being viewed as a knowledge telling process, where the students may know the content, or a knowledge regurgitation process, where they give words back to the teacher without understanding them, but rather a process, whereby they were able to construct the new knowledge" p.

536. Hein (1999, p.137) experienced that "using writing in introductory physics classes for non-science majors suggests that it can be an effective vehicle to allow students to develop their critical thinking and problem solving skills as well as deal with their personal misconceptions regarding a specific topic in physics." Hein concluded that the non-traditional writing activities encourage the students to make linkages between physics and their real life, and helped them sharpen their critical thinking skill.

In physics education the crucial problem is that approximately 50% of incoming college students' have not reached the intellectual stage of development at which they can think abstractly (i.e. scientifically) (Kalman, 2008).There are several reasons for this. The foremost reason is that the students' come into physics classes with misconceptions (Eger, 1992). The students' approach to physics content is detached from everyday life experiences (Redish, Saul, & Steinberg, 1998). Another possible reason is that the course design implemented in the physics course does not encourage students to evaluate students' epistemologies in the context of reasoning within the course (Atasoy, 2013). Several studies showed that use of a writing-to-learn tool in addition to other activities in physics classes improve student's conceptual understanding. Atasoy's (2013) study shows that the writing-to-learn tool helps the students to recall their pre-knowledge and helps them to explain the physics concepts logically instead of in terms of mathematical operations, so that the students can construct the new knowledge through writing. Kalman (2011) confirmed that the writing process in physics helps the students to develop a more holistic approach to the course and also helps them to come to a clear understanding of key concepts. In his book Kalman (2007, p. 30) argued that "writing-to-learn helps the students to learn how to learn and to apply what they learn, rather than

memorizing what an expert has established." Therefore this method teaches the students how to discover the concepts behind the text and solve problems on their own.

The above discussion revealed that the writing-to-learn tool inevitably helps the students to enhance their understanding of the concepts used in science courses. This learning strategy invites the students to ask questions. The students can explore their misconceptions or gaps through their writings and are able to minimize those gaps. They can make connection between their prior knowledge with the new ideas presented in the course. They can share their thoughts with the teacher or with their peers through their writing so that they are able to maximize their thinking level. A non-traditional writing-to-learn strategy is useful in the physics classroom. The current study will investigate how and in what way the non-traditional writing-to- learn tool, 'course dossier method' helps the students to understand the subject matter of physics. The next section will briefly describe this method.

2.1 Course Dossier Method

The course dossier method was first described in Kalman and Kalman (1996). Kalman (2008) noted that it is a writing-to-learn activity particularly useful for non-science students.This method has also been used in advanced science courses for regular science students. In this student-centered learning method, the students can explore their knowledge in a very different way. The purpose of the course dossier method is to help non-science students learn physical concepts without using mathematical formulations. The method includes several kinds of writing activities during the course and after the course. During the course students prepare preview sheets prior to the classes of the

week. After the week's classes the students write a 'critique'. The preview sheets or 'writing reflection' is equivalent to the planning phase of an essay, the classroom experience represents the research phase and the critiques would be the body of the essay. At the end of the course, the students write an essay (overview of the course) using certain procedures. These kinds of writing activities help the students to follow the lectures and help them to get a holistic picture of the course materials after the semester.

2.1. a. Writing Reflection

This activity is done by the students before coming into the week's classes. The one-page preview sheet is based upon reflective writing (Kalman, 2008) on the materials that will be covered in the coming week. Reflective writing is a writing-to-learn activity (Kalman, 2008) to help students develop a scientific-mindset, change their epistemological beliefs and enhance their deep thinking. This is an informal writing task in which students read the texts and write using their own words. During writing they relate the subject matters to their previous knowledge and life experiences and combine them with the new information; it's a special writing activity that responds to personal experience, event, situation or new information. Through this activity the students can ask questions to themselves, converse with themselves, and try to find answer to their questions. This active learning tool promotes students' scientific thought and helps them to understand the basic scientific concepts found in the textbook.

After rereading their reflective writing, they write a one page preview sheet or reflection. In the preview sheet or reflection the students will write two or three mini objectives or questions at top of the sheet that the students think should be covered in that

week and the rest of the reflection sheet consists of a summary of the topics to be covered in the same week. The reflective writing will not be marked, but the one-page preview sheet will be marked. If the students do not submit an adequate amount of reflective writing with the one-page preview sheet, then the reflections will not be marked. This writing helps the students to be familiar with the textual materials before the materials are presented in the class. This advance reading and writing gives them away to engage with the materials and provides them with an opportunity to ask questions about the materials. Every week this questioning encourages them to discover the meaning of the concepts from the classes (Kalman, 2007; Kalman, 2008).

2.1. b. Critique Writing

Critique writing is done after the classes of the week. The critique has various forms: for science students in a regular science course it would likely consists of a short introductory paragraph, followed by a presentation of what was covered in the classes of the week and in a course for non-science students, it would be a one-page essay. The essay would be written in a format that anyone who knows no science can understand the things. In writing the essay the students' pick one or two most important concepts from the lectures presented in the class in that week and then critically analyse those concepts on the rest of the paper. The critiques must be presented in properly written paragraphs using normal writing or 12 pt. font and as few equations as possible. The students' are warned that the marks are deducted for unnecessary use of mathematics and extra pages are not read (Kalman, 2008).

2.1. c. Final Essay Writing

"In courses for non-science students and in smaller, upper year courses, the set of 'mini-research papers' (critiques) can be enhanced by a fuller recursive and interactive approach to writing" (Kalman, 2008, p. 133).

After finishing the course the students gather all of their critiques and write a single overview of the course using the following procedures:

"First entries: Two friends, who are not in the course, read the collected critiques and make comments.

Second entries: The student rereads their collected critiques with comments and writes reflectively on the collection.

Third entries: The second entries are used to develop some common theme(s) that run through the work.

Fourth entries: The themes are developed into a draft of an essay of 'n' pages. (For upper year science course, this (n) would probably be three pages. For a non-science course with a final exam, five pages. For such a non-science course, where the dossier is place of a final exam, ten pages).The essay must be a critical examination 'covering' the entire course in terms of the themes based on material discussed in class.

Fifth entries: The two friends read the draft and record their comments.

Final entries: The draft is rewritten reflecting a reconsideration of the material especially in consideration of the remarks by the two friends. Suggested length 'n' pages, but there is no page limit" (Kalman, 2008, p. 134).

The students are informed that, the dossier will not be marked, if any entry is missed.

The following model (Fig.4) indicates that in the course dossier method the students are engaged with different kinds of writing activities; such as prewriting, drafting, rewriting, speaking, listening, and sharing with each other. Belenkey, Clinchy, Goldberger and Tarule, (1997, p. 26) pointed out "in order for reflection to occur, the oral and written forms of language must pass back and forth between persons who both speak and listen or read and write, sharing, expanding and reflecting on each other's experiences." Therefore in this method the prewriting, drafting, and rewriting are the movement of going backward and forward, and backward again, from jotting down initial conceptions to drafting the work to regeneration of new ideas and new formats (Kalman, 2008).

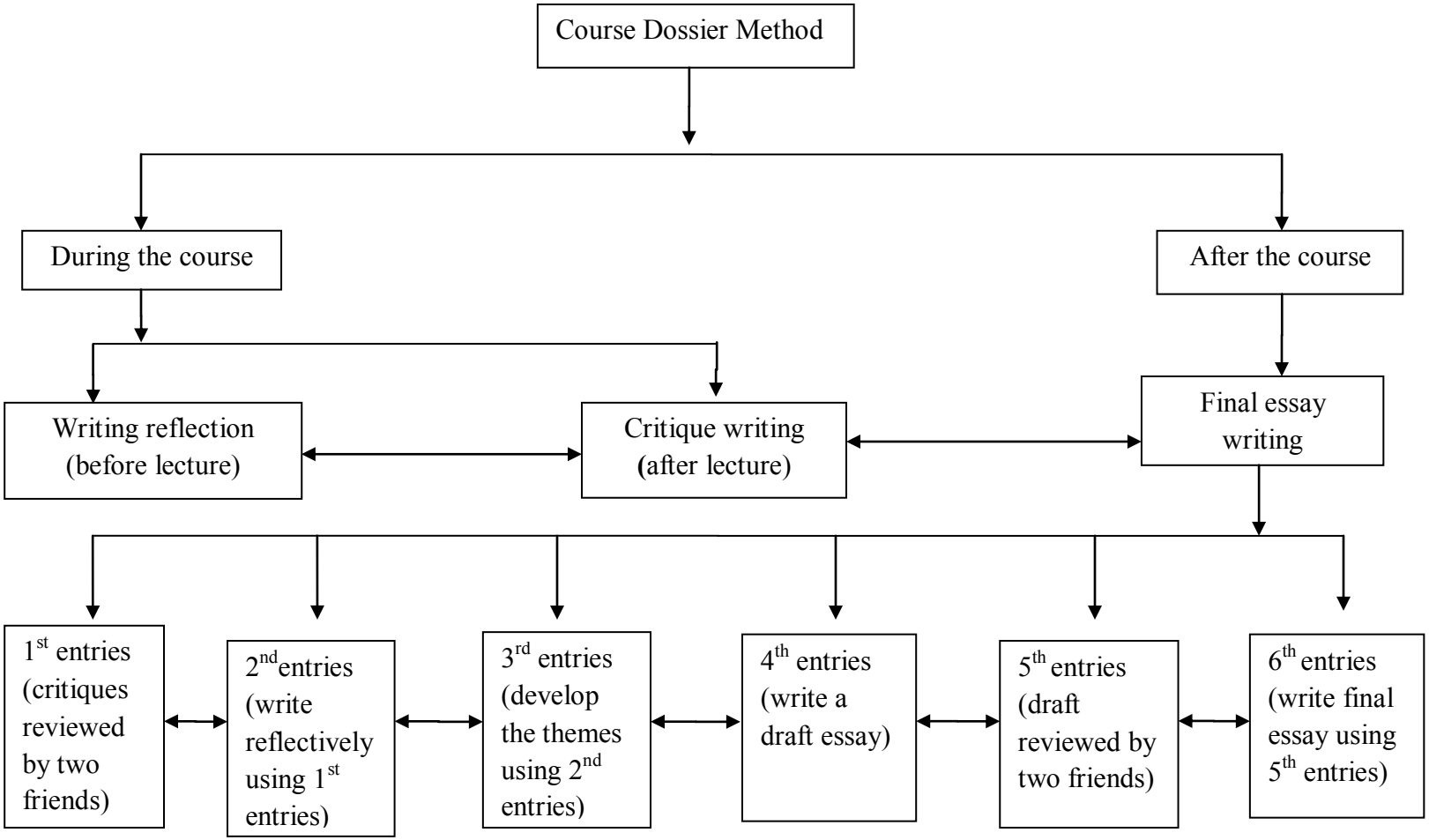

Fig.4: The Model of the Course Dossier Method

In the course dossier method the students are engaged with the activities in the manner of Gadamer's version of the hermeneutical circle. During the course the writing reflections before the class give the students the opportunity to examine their pre-concepts. In critique writings after the class, they can use their preconceptions found in the textbook and from lectures. Therefore, they can re-examine their concepts through this writing. After the course the students review all of the critiques in writing the final essay with six entries. The students examine and re-examine their pre-concepts over and over again; and can combine the pre-concepts with new ideas through this method. These activities engaged the students in a hermeneutical movement.

Moreover, the course dossier method gives students the opportunity to share their thoughts with the reviewers. The students examine and re-examine their understanding of the subject matters with the reviewers' comments. The students can scaffold their knowledge with the help of these peers according to Vygotsky's notion of social constructivism (1978). The students can decide individually what is important to understand and actively can construct the new knowledge with the interactions of others (Wink & Putney, 2002). In the next chapter we investigate how and in what way the course dossier method helped the students in understanding the subject matter using the mechanisms of hermeneutics and Vygotsky's social constructivism.

Chapter 3

Data Analysis

In this chapter, section 3.1 briefly describes the data collection methodology and the methods of data analysis. Section 3.2 describes the data analysis of four interviewed (non-science) students' interviews and their writing products. Section 3.3 describes the data analysis of non-interviewed (non-science) students' writing products. The data analysis of science students' writing products are described in section 3.4. Results and discussion of the analyzed data are briefly described in section 3.5.

3.1 Methodology

In this multiple case study (Yin, 2014; Stake, 1998; Merriam, 1988), the participants were selected from two courses from the department of Physics at Concordia University. The students taken from the course PHYS 200 (From particles to Galaxies) in the winter semester 2014 and from the course PHYS 456 (Classical Electrodynamics) in 1995.The course PHYS 200 was offered for non-science student. The course curriculum of PHYS 200 consisted of very basic physics 'from motion to particle physics'. The course was designed as 20% marks for reflections, 20% marks for critique writings and 60% marks for the final essay in lieu of a final exam. Students were taught this course without any mathematical problems or deriving equations. The course PHYS 456 is regular course for physics students. The course design for this course was 20% marks for assigned problems, 20% marks for course dossier, 30% marks for midterm and 30% marks for final exam. In both courses, students had been instructed about the method at the beginning of the semester. As mentioned previous chapter, the part of the course dossier involved two reviewers who are not enrolled for the course to comment on the critiques

and the draft of the essay, so the students were asked to write the critiques and essays in a manner that a general audience can understand.

Semi-structured interviews (Merriam, 1998) were conducted for collecting the qualitative data for this study. There were four participants taken from PHYS 200 course for the interviews. Two interviews were taken for each participant in this research. One was (pre-interview) conducted at the beginning of the course and another (post interview) was conducted end of the course. The two sets of interview questions (see Appendix C) were designed to explore 'in what way the students' understanding of the concepts of physics improved by using the course dossier method. All interviews are videotaped and transcribed. Students' code names (AR, JS… etc.) were used to preserve anonymity.

Once the transcriptions were completed the 'within- case analysis' recommended by Stake (1995) was followed to analyze the interviewed data that provided the detailed description of each case and the themes within the cases (Creswell, 2007). The analyzed data were tabulated based on the units- what was the change in students' understanding of the subject matters at end of the course compared to early of the semester, how helpful the reviewers' comments were to discover the misconceptions or new things, in what way the course dossier method helped the students to improve their understanding of concepts of physics and if there were any change of the students' views of physics after using this method. The writing products (course dossier) were also analyzed by 'within- case analysis' method for each individual case following the same process as described above for the qualitative data. Short discussion was given for each case (interviewed students) by comparing the interviews and the writing products, what they said in the interviews and if what they said is supported by what they did in their writings products. The writing

products or course dossiers of 11 non-interviewed (non-science) and 3 non-interviewed (regular physics students) were analyzed individually in the same way followed by the 'within-case analysis' method. Once the data analyzing was completed for individual cases, an overview of the analyzed data was tabulated and the cases were compared using the method of 'cross-case analysis' (Stake, 1995). This analysis helped us to know how helpful the course dossier method was for non-science students to learn the concepts of physics and also for science students; and in what way their understanding of concepts improved; if changes of understanding of subject matter of physics experienced by non-science students was similar to those changes experienced by science students in using this method.

3.2 Data Analysis of Interviewed Students (Non-Science Students)

Case JS

Data analysis of interviews: This student's major was communication studies. The transcriptions of pre and post interview showed that at the beginning of the semester he liked reflective writing because he thought that's a good work and will clean his mind. In the pre-interview he believed that the method will work; it's an interesting method. In the post-interview he stated that he especially liked the critique writings. He also thought the idea of reading over the critiques after the semester is good because from here he can discover some concepts that may help him to write a more concrete paper at the end. In the post interview after the semester he also said that reflective writings were helpful. He actually found comfort with this writings and he was surprised. He thought these writings engaged him with the materials of the course because he read before the class and then did his reflective writing. Consequently, he was attentive to the class. He also noted that

the reflective writing was interesting and also was helpful in writing his critiques after the class because a lot of the same material reappeared during the semester. He also liked the critique writings more than the reflective writings. He thought that the critique writings helped him to review the materials during the semester and also after the semester in writing the final essay. It helped him to think about the course materials. Looking back at the critiques was very significant because he had to go back to the course materials; he found overwhelming and he re-examined the concepts again, which gave him a very clear path in writing the final essay (Table-2). Moreover he thought the reviewers' comments were very helpful in explaining the concepts better because they found mistakes but he was not able to use all of those comments in explaining the concepts because of lack of time. He also thought the second round comments on the draft were very practical although he couldn't fully make use them because he was so busy at that time with exams. The second entry the free writing part was also helpful to write about the whole course. Overall he thought the course dossier method helped him to review the course materials and to understand the concepts better. It was really an interesting process for him and a very different learning method. He thought this course has changed his perception about science, because before he thought science is just straight forward. Now he really realized science is two steps forward and one step backward.

Data analysis of writing products: Most of his critique writings earlier in the semester showed that, he found out the important concepts covered in the class, but the explanations about those concepts were unclear (Appendix A: JS-1). His later critiques were more understandable. In the eighth week, his clarification about the expansion of the universe relating to red-shifting exemplified this: "the constant expansion of the

universe (Hubble's law) means that the distance and speed at which other bodies are from earth changes, and thus so does our ability to observe those bodies. Red-shifting accounts for this. This is highly important because not only do we know that there is a changing special-temporal relationship between us and other bodies, but furthermore because we can quantify that relationship and represent it accurately."

In the 9th week of the semester he talked about the Grand Unified Theory, which he did not explain well at that time: "In a GUT, paradoxically, the constants change; all matter is flat lined into sameness. And this only happens as we peer back into time. Thus the addition of time as a variable, not a constant, is my concept for this week". The explanation of this concept in the final essay is better: "in the current state of our universe, different laws govern the ways these particles interact on different atomic levels. The interaction of quarks is governed by the Strong Nuclear force. The interaction of Leptons is governed by the Weak Nuclear force. However, the way physics has peered back through history, as it were, reveals the importance of synthesis to the scientific project as a whole. In the Grand Unification Era, all forces (except for gravity) were equal and all particles (except for perhaps, hypothesized graviton) interacted in the same way".

Some of the concepts, which he derived in his course dossier improved. However his final essay was mostly written in a manner of the philosophical relationship with the laws or theories in physics rather than explaining concepts, because he didn't use all of comments given by his reviewers as he was busy with other courses at that moment, though some of the comments were very significant for him in explaining the concepts and helped him to write a better final essay. For an example in the eighth critique one of

the reviewers suggested "can you relate these two concepts (red-shifting and the eternal presence of radiation) to dark matter?" (For more comments see Appendix A: JS-2). His course dossier also showed that he didn't make use of the comments from the reviewers on his draft due to lack of time. His views on science are also revealed in his final essay: "it is still emblematic of the fact that science is progress; it is a process of induction and deduction, synthesis and discord, and prejudice and surprise findings. It is an evolving question for knowledge that seems to follow the maxim 'two steps forward, one step back'." (See Appendix A: JS-3 for another view)

The above analysis showed that his concepts of physics improved using the course dossier method. The critique writings gave him a clear path to explain the concepts better in writing the final essay. The critiques were also very significant for him to review the materials during the semester and also after the semester. Different entries were helpful for him to write the final essay specially the free-writing part and some of the comments from the reviewers. Free-writing engaged him to the materials of the course again. Although the reviewers' comments were very useful but it was not possible for him to use all of them as time was short in explaining things further. This student's final grade is A. It would have been possible for him to get an A^+ if he had the time to pay more attention and use the comments properly. Overall this method really changed his views on science and helped him to grasp some general concepts of physics in a very different learning way.

Case TS

Data analysis of interviews: His major was History. The pre-interview transcript (Table 1) showed that at beginning of the semester he thought the purpose of the course dossier method is to reflect and absorb the course materials each week and bring up all of those materials at the end to write a final paper. He also thought the method is very good because it would give him an opportunity to explain and review all the concepts and may help him to connect or link those concepts together. The post interview showed (Table-2) that he liked the idea of reflections because it allowed him to become familiar with the materials before the lectures were presented in the class. He also said the reflections before the class made him curious to read over the textbook. The reflective writings helped him to form his own ideas about the materials in the class. This writings also helped him to bring some questions to the class and get the answer to those questions from the class. He also thought it helped him to explain those materials and helped him to understand them better.

He thought the critiques opened up his eyes about science because he found common themes after reviewing the critiques. He thought the critiques were very useful in writing his final essay because there was the opportunity to read over the materials again and this helped him to understand the course material fully. Moreover he thought the reviewers' comments were very helpful because of their analysis of the critiques. He noted that he really liked the course dossier method because it enabled him to approach the course in a very different way. The overall course dossier opened up his eyes and his mind about physics because this method caused him to think about concepts rather than memorizing facts and the whole course gave him a better perception about physics. He thought this

method is as an "overall evaluation what physics actually is and what science is in general." He said his perception about physics really changed after the course because before taking this course he thought physics is basically related to speed, velocity, or force; after the course he realized that physics is everything around us.

Table 1. Students' Approaches to the Course Dossier Method Beginning of the Semester (Pre-Interviews)

Students	Students' personal views about the Course Dossier Method before the Semester
JS	"I would say it is a good method, it sounds interesting … I think it's an idea like having other people read over here critiques and sort of discovering some concepts."
TS	"I think it is a good method to use, because as I said you can reflect on what have learnt from the whole semester every week."
DC	"I think it's a good work."
LL	"I don't know right now, what is the purpose of the professor at least, so yea maybe later we can know."

Data analysis of writing products: This student's earlier critique writings showed that he picked up the very important concepts from the course materials presented in the class, but could not explain them clearly during the semester. As an example in the fourth critique he wrote "light was believed to be a particle back in Newton's time. Newton's conducted few experiments to conclude whether this theory was true. One was to pass through a medium, what occurred was part of the light would bounce off and go perpendicular and another part would refract through the medium." But he did not explain this concept further. Later on his concept writings were improved. In the eighth critique he talked about the Cosmic Microwave Background Radiation (CMBR) and explained the evidence of its presence in the universe: "not long after the big bang, the universe was filled with highly energized particles ... This caused the particles to get extremely hot, so hot that electrons were unable to attached to them and create atoms.

Eventually the particles cooled down and atoms were created, this meant the particles could no longer reabsorb the radiation. This radiation eventually condensed into the Cosmic Microwave Background Radiation. This radiation is still around; here's an experiment to try, hook up an old television to an antenna and find a channel ...even though there is no station interference? A small amount of the static is caused by the CMBR." (See Appendix A: TS-1 for another example).

Very good and useful comments came from the reviewers. For an example one of the reviewer's commented on his ninth critique: "you explained theory#1, but didn't explain theory #2 or 3. How does this prove that the Big Bang theory is correct?" where the student wrote "there are three pieces of evidence that support the Big Bang theory. The Cosmic Microwave Background Radiation which is when energy particles radiated and then absorbed the energy. These particles cumulated into hot electrons which formed a plasma filled universe. After the universe cooled down, the matter became atoms. The second is the abundance of light elements in the universe and the third is the prediction of the number of generations of quarks and leptons." (See Appendix A: TS-2 for another example). This student did not use those comments further to elaborate that part in writing his essay. He just copied those parts rather than explaining the facts in the essay. He understood that he had made a mistake in the critique as he said in the second entry of free writing based on reviewers' comments (See Appendix A: TS-2), because one of the reviewer commented on that part (See Appendix A: TS-3). Although this student identified what were mistaken in his critiques or which parts he need to explain further in writing the final essay, he did not make use of these comments at all. This student only

used the reviewer's example 'perception' (given on his critique) as one of the theme of the course and elaborated that theme (See Appendix A: TS- 4) in writing the essay.

After analyzing the transcriptions of the interviews and his writing products, those showed that the course dossier method helped him to understand the general physics or physical laws/theories and improved his concepts. Based on the reviewers' comments he found out a theme 'perception' of the course that made him easier to write the essay. Overall this method was useful for him to improve his concepts of understanding behind physics and changed his attitude about physics after the semester. This student's final grade is A$^-$. It would have been possible for him to have a higher grade if he would have followed the reviewers' comments properly and explained the facts further and paid attention to the missing parts in writing the essay.

Case DC

Data analysis of interviews: His major was religion. In the pre-interview he said that the course dossier method will work well. The reflective writing part will be helpful for him. He also said the critique writing is not an easy process, but if he give more effort it would be helpful for him. The post interview showed that he thought the reflections forced him to read the textbook. He said these writings also helped him to bring questions to the class and helped him engage with the class presentations. Also he thought this advanced writings (reflective writings) helped him to think of the materials in the class again and helped him to pick up the important concepts from classes. He thought that writing the critiques was challenging for him, because he found many concepts to understand and did not try to explain those concepts in a critical manner. So in writing

the critiques he was just summarizing or paraphrasing the facts from the book in his own words. But he thought if he tried to be more critical in writing the critiques that obviously would be better for him. He thought that different entries were helpful for him in writing the final essay. He said rereading his critiques with the reviewers' comments after the semester helped him to find the themes of the course and guided him to think about the concepts in writing in the final essay (Table-2). Moreover he thought the reflective writing part (the second entry) was very helpful for him in finding the themes of the course and caused him to rethink about the concepts. He guessed the reviewers' comments were not too helpful for him because he thought his critiques were written in a manner of summarizing the facts rather that explaining the individual concepts or insightful concepts. So his reviewers did not understand all the facts clearly. He said that he asked them to give him some themes or general comments about the concepts. He also said when he was reading the reviewers' comments he discovered many questions about science which motivated him to write something better. Moreover he thought the main issue of course dossier was the critiques. This learning method is a way to review the concepts and to learn something new by going over the course materials again.

Data analysis of writing products: During the semester this student tried to pick up the concepts from the lectures, but the explanations of those concepts were not written clearly and were mostly summaries. For example in the eleventh critique he talked about the expansion of the universe (See Appendix A: DC-1) in a way that did not seem to make sense. The reviewers' comments were not very useful to him in writings the essay, but helped him in finding the themes of the course. For example one of the reviewers pointed out themes such as "Themes: experimentation, development of scientific method,

opinion and biases of scientists are important to consider...", "Determinism: how ideas have changed from the belief that everything in the universe" (1st entry). He used those themes in writing his essay. The reviewers did not give him many comments; he missed five critiques out of twelve critiques. So it was hard for the reviewers to make good comments on his critiques. Consequently that was a big challenge for him and it was not possible for him to clarify all the concepts.

The interviews and writing products showed that overall this method helped him to understand the general ideas in physics as he wrote in his essay "this course has taught me a lot more that just facts about physical phenomena, it has shows how physics works fundamentally." Especially writing the critiques helped him more as he thought "those (critiques) guided the kind of the conceptual thinking to write the final product" (post interview). The reviewers' comments were helpful for him in finding out the themes of the course. Moreover the free writing part was helpful for him to find the themes in writing the essay. His final grade was B-. It would have been possible for him to have a higher grade if he had paid more attention and properly followed the method. He did not hand in five critiques and did not try to explain the concepts in a clear manner. Therefore his reviewers did not understand the concepts clearly and it was difficult for them to provide useful comments. But the reviewers asked many questions about his critiques and those helped him to discover some new facts behind physics and motivated him to improve his writing in the essay.

Case LL

Data analysis of interviews: Psychology was his major subject. The pre-interview showed that early in the semester he thought the course dossier method is some kind of psychological experiment to examine the students' concepts. The post interview showed that the reflective writings made it easier for him to write the critiques. He said he really did not bring up physical things in his critique writings, so his critiques were not clear to understand the subject matters. He said that he didn't take the course very seriously, so he made many mistakes. He also said that he was not careful in writing his final essay and his reviewers' didn't give him meaningful comments because they were very busy at that time, so his draft and final essay were similar. Nonetheless he thought the whole idea is very nice, because students found out a lot about physics concepts. He also thought that this method is really rare in the educational system and can help the students' to think deeply and can help make links to the real life.

Table 2. How Helpful was the Course Dossier Method to understand the Basic Concepts in Physics (Post Interviews)

Students	How helpful was the Writing Reflections in Understanding the Concepts	How helpful was Writing the Critiques in Understanding the Concepts	How helpful were the Reviewers' Comments in further Writings	Students' personal Views about the Course Dossier Method after the Semester
JS	"I found comfort actually; I was surprised. It was helpful…because you engaged with the materials".	"I like the critiques lot actually... more than the reflection...because it helps to review the materials".	"I think the comments were helpful, explain the things better…they found mistakes that was helpful but could be more helpful like it is bit of just a practical struggle just because of time".	"I found it's a very interesting process and did help me like better understand the things specially revisit some concept through all critique… it was different. I never took anything like that before".
TS	"I like the idea of reflection because it allowed us ... what will gonna happen on the next week and it allowed us to... form ideas of the material and come up of the questions".	"I think it had very good impact because of I have been read over my critiques after course ...and understand fully what was have been talked about and ... helped me the writing of the essay".	"They were very helpful ... and they helped me to come up with the themes with my course dossier and I use their examples in my essay".	"I really like that method, because it's gives the students',... change to approach the class in a different way, I think the point was to allow us, to open our minds about physics, not just memorize..."
DC	"I guess it forced me to read ahead. I guess may be given me some questions to bring up them in the class...to keep you engage in the lectures".	"I guess yea, they (critiques) guided the kind of the conceptual thinking to write the final product".	"I just asked them (Reviewers) to tell me about themes or general comments about the things I understood. I guess it's good, motivated me to write something good".	"The common issue is critiques ... I guess kind of helps you to your search for questions and inside in".

LL	"The critique would be easier for me due to influence of reflective writing".	"They didn't give me very meaningful idea because we are all busy so later on I just follow the schedule ... and my first draft and second draft is very similar".	"The whole idea is nice ... and that's really rare in educational system and it help me ... it's just wonderful like you can think in deeper and link to your real life."

Note: See Appendix B: Table 9 for more information.

Data analysis of writing products: This student's course dossier showed that his concepts did not improve at all during the semester and after the semester, because he did not follow the instructions for the method. During the semester he submitted only seven critiques out of twelve. His critique writing materials were not related to the course. For example in the fifth critique he picked up the concept 'Copenhagen interpretation', but the explanation was very unclear and not related to the course materials. (See Appendix A: LL-1).

This student did not complete all of the entries of the course dossier. He missed the first entry - there were no comments from the reviewers. He also missed the fourth entry in which the themes are developed to use in writing the essay. He did not find any themes of the course to use for writing his essay. All through the draft he mostly described his psychological views, which were not required for the course and although he wrote something related to physics the ideas were vague. In the fifth entry his reviewers provided very short but good suggestions after reviewing his draft, but he did not follow those comments in writing his final essay. For example his reviewers told him: "I had read your course materials, the things you are talking about is not science! You should use the some of the materials..." "Show some fact related to the course." So his draft and final essay was the same.

The above analysis showed that his concepts of physics were not improved because he did not try to follow the course dossier method at all and his reviewers did not give him comments on his critiques, because they were so busy at that time. Afterwards they gave very short, but good suggestions on his draft. However, this student did not use those comments to rewrite his essay. He also said the course dossier method is wonderful

for the educational system because in this method students can think in deeper and can make link in their real life. So he agreed that the method is useful and good to understand the facts in depth. He received a failing grade, but it would have been possible for him to get a passing grade if he had followed the method properly; took this course seriously; paid more attention to the materials; be careful to do the different steps of the method and approached this course as a science course.

3.3 Data Analysis of Non-Interviewed Non-Science Students' Writing Products

Case AR: This student realized how helpful it was to revisit the materials and also reviewer comments on his critiques and the draft of the final essay for further writing. He found some crucial themes of the course, which he used in writing his final essay. He tried to explain these themes in a logical manner to understand his approach to science, scientific laws or theories and the concepts behind them. It was easier for him to rethink the subject matter and explain them conceptually using the comments from the reviewers. As an example, in the fifth critique he mentioned Einstein's proposal of the particle theory of light. One reviewer pointed out to him that he did not elaborate on the meaning of the concept behind the theory, what was Einstein's thought or how did Einstein explain that light behaves as a particle etc. Consequently in the final essay he gave details about how and in what way Einstein's particle theory of light was explained: "he (Einstein) proposed that the energy of light is not evenly distributed along a wave of light, but rather is found in small, evenly spaced pockets. This could not be explained by wave theory."

He thought the reviewers' approaches were entirely different than his own because they asked many questions and wanted to know what they didn't understand. This motivated him to discover the missing parts in his critique writings, as he asked "it was also incredible to see the relationship between particle physics and the universe, didn't get much into it in my critiques but I want to look into it more in the overview" (1st entry). In the critique writings he just defined the different particles, their properties, historical background of the discovery of them, but did not explain the role of the particles in the origin of the universe, what is the concept behind them, how they interact with other particles or what forces are responsible for their interaction etc. In the final essay he used particle physics as one theme of the course because he thought "the sheer amount of knowledge I picked about particle physics is simply staggering that definitely has to go in there" (final essay). A large part of the final essay was a discussion of particle physics. Not only the concepts behind particle physics but also quantum mechanics were explained in more detail in the final essay (See Appendix A: AR-1) than in his critique writings. He thought it is necessarily to discuss quantum mechanics before talking about particle physics.

In reading the reviewers' comments he discovered missing items in his pre-writings. The course dossier method engaged him to review the materials again and again. During the semester student AR tried to become familiar with the concepts of physics or physical laws or theories. When he had the time to go through the critiques again he expanded his thoughts about the concepts found in the critiques. It was possible for him to make a link between quantum mechanics and particle physics and also to understand physicists' views about the universe. Overall his depth of understanding improved and his views on

science changed after completing the course. He expressed his own realization after finishing the course, "I have to say that this has been an incredible experience. It has opened my mind to many of the inner working of the universe, both on the sub-microscopic level and on the galactic level. It was even more incredible to see just how closely the two related. It forced me to think not just about the laws of physics around us but about the forces, interactions and theories that shape these laws."

Therefore, it was possible for him to understand the basic concepts because the course dossier method forced him to pick the concepts behind the scientific laws and theories and to explain them, combine them or to link them one another. In his second entry in the course dossier he noted that in high school, he had difficulty putting together solutions especially those requiring a lot of 'outside-the-box' thinking, because he didn't know the concepts behind the equations, he just memorized them. But his views of science and his approach were changed when "professor Kalman hit the nail right on the head when he talked to us about the difference between rote learning and true understanding." The idea of rote learning is a technique of memorization based on repetition that one will be able to quickly recall the meaning of the materials. On the other hand true learning is conceptual learning based on a student's own experience or thought about the subject materials. In the final essay he got 90% of the total mark but his final grade was B^- because he missed some critiques during the semester.

Case AV: His major was philosophy. In the course dossier, his concepts originated from the philosophical idea of scientific revolution. He made a very good comparison of the Baconian philosophical method of science and the Newtonian hypothetico-deductive method of science in the post writing (free writing) part of the second entry. This had not

been explained well in his critique writing earlier in the semester. But after rereading the critiques he noted that "this makes me realize that a fundamental difference between Bacon's and Newton's methods that I didn't consider in my critique is how Bacon's method seems more based on an individual's understanding of what is observed, while Newton's method involves the responsibility of demonstrating to other scientists that what is being observed is explainable and that the explanation can be questioned, and if found to be lacking, it can be improved."

This student made a relation between the new ideas he learned in the course with previous knowledge. He wrote "this is where (4^{th} critique) I start to see more connections to my previous critiques that I did not initially anticipated." In the second week he learned about fruitful theories, at that time his concern was why should a theory be fruitful! But later when the model of solar system and wave-particle nature of light was presented in the class, he understood that: "I think we could consider this (Einstein's photo electric effect) to be a fruitful theory in that it incorporates old facts (Lenard's idea) with new one. Since light could be demonstrated as having particle and wave properties (being dispersed as 'quanta' but moving like a wave as demonstrated in previous experiment), Einstein's conception seems to provide the strongest case for the nature of light." Further he explained why a fruitful theory is more beneficial than other scientific methods which may help us to formulate a realistic picture of science (see Appendix A: AV-1)

Reviewers' comments on his critiques and on the draft of the final essay helped him to rethink the concepts and also assisted him in writing a better final essay. For an example in the critiques, he cannot clarify what the red-shifting is and how this idea helps

scientists predict that the 'universe is expanded'. He just noted that "astronomer V.M. Sliper began to make observations in which spiral nebulae were 'red shifted', appearing to have an increasing reddish colour. This was eventually determined by Edwin Hubble in 1927 to be the result of increasing wavelengths, which indicates an increasing distance between the Earth and redshifted objects under observation." In the first entry his commentators' statements were "why does red shifting mean that the universe is moving away?" "What wavelengths are increasing when 'redshifting' occurs?" It was explained well in the final essay: "observations made by Slipher in 1912 revealed the phenomenon of 'redshifting', where the light of stellar bodies is shifted to the red end of the spectrum, indicating an increase in wavelength. Further study by Hubble later revealed that the nebulae observed by Slipher were quite distant from the Earth, and even more remarkably, that those galaxies were receding from our own (the further away, the greater the speed at which they did so)". (See more comments in the Appendix A: AV-2)

Another crucial point that did strike his mind was the importance of 'collaboration and peer review' for scientific research. He brought up the 'Rogerian Arguments' (Appendix AV-3) and tried to explain his concepts within the realm of scientific discovery. For an example he wrote "The formulation of quantum mechanics proposed by Heisenberg and Schrödinger can be considered scientific progress as the result of collaboration and peer review, to the point that Schrödinger was able to calculate that his wave mechanics and Heisenberg's matrix mechanics were actually mathematically equivalent" (Final essay).

Moreover, this student discovered the necessity of 'misconception', which is significant in science and science education according to Eger (1992). This student termed 'misconception' as 'error' and clarified mistakes might be advantageous features

in science as it can provide the new idea or knowledge, and give us an efficient way to conduct further experiments. If there is no bias or error to deduce laws from observed data or hypotheses there is no reliable way to develop new knowledge or prove the existing theory. He pointed out the case of wave-particle duality of light where debate or bias helped the scientists to think about new findings to prove the reliable result.

His final grade is A^+, which implies that his concepts were improved after using the course dossier method; because it gave him an opportunity to find the actual thought behind the course materials again and again. The reviewer's comments also benefitted him as those gave him a way to discover the missing ideas in the critiques. Moreover it was possible for him to make a connection between the ideas found in his earlier critiques with new thoughts that he discovered later on in the course. This method motivated him to pick up the basic concepts in physics every week. His views on science really developed after studying this course. This is shown by his statement (3^{rd} entry) about the benefits of collaborations in scientific work and utility of misconceptions to learn physics or science (See Appendix A: AV-4). Therefore, as a non-science student it was possible for him to grasp the overall concepts of science using the course dossier method.

Case BDS: This student's major was English and Creative Writing. His earlier critiques showed that, he picked up the basic concepts from the course materials and lectures presented in the class, but his explanations were a bit unclear. In the second critique he wrote about Newton's law and natural forces: "the introduction of Newton's laws as a fundamental and widely accepted understanding of natural forces is hugely influential." He didn't expand on what he meant by this statement. Later critique writings are more detailed. The concepts are, however, not entirely correct. The ninth critique

contains an example: “if the physical limit of the universe could be ‘objectively’ known then perhaps expansion, gravitational waves, and ancient radiation could be more precisely traced back to the ground-zero of existence. So while looking at CMBR certainly is helpful in inducing what might have happened at the early stages of the universe are known (in a Euclidian, or 3-manifold sense)-at which points working backwards might be definitely a plausibility, or our conception/understanding of time alters to allow for an explanation of matter at the literal instant the universe began, there will always be holes and issues with the Big Bang theory.” (See Appendix A: BDS-1 for another example.)

His views on physics were also changed as the course progressed. For example he said “Originally, prior to this course, I had thought that this (Quantum Mechanics) strictly opposed a classical, mechanical and deterministic view of reality, one which on a philosophical level precludes free will and choice and says that everything is predetermined. Quantum mechanics and the uncertainty principle do not inherently go against this, though, and indeed the two are somewhat compatible. Essentially, I now understand the uncertainty principle and quantum mechanics to be a predictive theory rather than a descriptive one, and this makes all the difference.” (6^{th} critique) (His views continued to evolve as the course progressed. See Appendix A: BDS-2.)

The reviewers’ comments were very helpful for him in writing his final essay. Both of the reviewers asked many questions about the critiques. For example one of them asked; “do you think science is the pursuit of existing structures in nature or a means of organizing that which we observe of somewhat in between?” (See Appendix A: BDS-3

for another example.) In the final essay he tried to answer those questions and explained his thought of science in detail. (See Appendix A: BDS-4.)

Overall, this student's ideas about physics were changed after using the course dossier method. His personal realization "seeing myself re-examined cosmic inflation after having investigated in a few weeks prior I realized that the didactic methodology of the critique/reflection process was way more efficient and useful ... At the start, I thought this weekly writing exercises would become a chore and have little effect on my understanding of the concepts. ..... The set up for the class in itself appeared to have kind of isomorphic, epistemological process with the very discoveries I was learning about" (12th critique). He later wrote (in the final essay), "When I first signed up for this class on particles and galaxies I thought of how strange it was so distinct categories were to be presented alongside one another in a singular class and didactic process. After several weeks of the course materials, however certain themes started to emerge and different general approaches to scientific knowledge became more apparent. And while the subject matter still seemed to contradict itself at times (by the end of the course it was clear the theories of general relativity and quantum mechanics are still somewhat non-syncretic) the underlying commonality of the nature of scientific development held the two domains closely together." This course enabled him to discover the real concepts behind the physics or physical laws and theories. Not only the critique writings but also the comments from the reviewers' were very useful and effective because the comments were very logical and inspired him to review the materials again.

Case CR: Early in the course, his critique writings were written in a manner that mostly described the historical development of the physical laws or theories rather than

explaining the concepts behind these laws or theories (Appendix A: CR-1). Later he included discussions of concepts. For example in the tenth critique he discussed Grand Unified Theory and wrote "in discussing the earliest phases of the universe (earlier than a millionth of a second) we examined the evidence for the affect of temperature on plasma and the manifestation of matter in this temperature change. 1/10^43 seconds after big bang we can begin to theorize today with some understanding but the information cannot be fully understood. It is here that the quantum gravity barrier arises. 1/10^35 seconds after the big bang GUT's can be derived at and understood, in a theoretical sense 1/10^6 seconds after the big bang there is evidence for the formation of protons and neutrons. From this point in reverse we can see evidence for increasing unification and symmetry, meaning that the earliest cosmic plasma contained all properties simultaneously" (see Appendix A: CR-2 for more quotes).

It was easier for him to write his final essay because many good comments on his draft came from the reviewers. The reviewers suggested that he needed to revise some sentences to clarify some words, which were not understandable. For example in the draft he wrote "one way in which idealization is further towards the middle of the spectrum of pure observational deduction and fantasy is that idealized theories are still inherently based in some part on observation or experience" (Reviewer's comment: "revise this sentence, what do you mean by the spectrum?"). In the final essay he rephrased this as "yet we start to recognize that there is a spectrum of the methodologies applied to scientific pursuit; a spectrum that ranges from pure observational deduction to pure imaginative fantasy." Moreover it was possible for him to add a very good introduction (Appendix A: CR-3) in the final essay, because the reviewer's suggestion was "maybe

add an introductory statement or paragraph" (there was no introductory paragraph in the draft).

During the semester many conceptual questions came to his mind, which forced him to rethink those questions after the semester. In the critique of week six such a conceptual question was "the microcosm may be that which we are composed of, but how could it possibly be properly conceived by perceptions which are engineered for the macrocosm?" In the final essay he used 'microcosm and macrocosm' as a theme of the course and explained it in a very logical manner: "in the past century or so, the world of physics has advanced to the point of being able to explain the microcosm and macrocosm of the universe from the tiniest to the grandest of scales we have yet observed. We move away from examining that which is immediately observable to us, whether with or without the aid of advanced technology, and into the dissection of the atom and the mapping of super-clusters. What is incredible seeing the reflection of the microcosm realm in the macroscopic realm? Inflation, a relatively concept, is an excellent example of this idea." (See other example in the Appendix A: CR-4)

His views on science were also changed after studying this course. He expressed his thought in the second entry of free writing as "I always took the stance that western science was overly exoteric meaning it looked too much to the outside to find answers and meaning and thus altered and skewed our perception so as to expect certain answers and not be accepting of the mere mystery of things that is best understood through experience and looking within-I still believe all this to be true, but after taking this class I have a new found appreciation for the arduous experimentation and philosophizing that was occurred for centuries within the mind of scientist, philosophers, physicists and

mathematicians who have had incredible gift of undying curiosity and perseverance to see the mysterious things."

This student's course dossier showed that his level of understanding about the course materials improved because every week the critique writings motivated him to discover the actual concepts behind physics and physical laws or theories as he expressed "this class really worked well as an introductory course on Physics as it provided us with an extensive history and a basic understanding of the theories and principles that have been put in place but more importantly it explained how those principles had been arrived at."

Not only the critique writings but also the reviewers' statements in the first and fifth entry played a significant role in the writing of his final essay. With the aid of the reviewers' comments, it was possible for him to present the final essay in a conceptual mode. Moreover, his scientific belief system was also changed as this course was given in a manner without applying complex mathematics to present the theories using philosophical background of physics to understand the whole bunch of it. Therefore it was possible for him to get A^+ in this course. His personal thought, "In my overview of the class as it was not our focus in the lectures, I found my own personal believes shifted somewhat. I am grateful for having taken this class as it opened my mind to scientific approaches to things."

Case EW: She did not enrol for this course. She audited this course because of her interest in the concepts behind the structure and origin of the universe. Assessing her course dossier it showed that concepts in her later critiques have been explained better than in her earlier critiques. For example in the third critique she talked about Galileo's

views of straight line motion and consequently the discovery of Newton's law of gravity as "Galileo changed our entire view of natural motion, from a circle to a straight line motion. This concept of motion as a straight line was big; as it later led Newton's to consider forces, which indirectly influenced his discovery of the law of gravity." Here she did not explain clearly why this motion is a big concept and how Newton came to consider forces that influenced him to discover the law of gravity. In her eighth critique she explained the concepts of red-shifting and the expansion of the universe fairly well: "Hubble noticed that the Red Shifting of certain objects in the sky not only indicated their very large distances from the earth, but also the speed at which they are receding from the earth. These distant galaxies were moving away from us! Further, Hubble noted that there was a correlation between the distance of an object and how quickly it was moving; the further it was, the quickly it moved away. This meant ... our universe is in fact expanding." (See Appendix A: EW-1 for next paragraph and also for another concept).

Some concepts, which she did not explain clearly during the semester, were written well afterwards in the final essay. For an example in the sixth critique she picked out the concept of the Heisenberg uncertainty principle: "Heisenberg uncertainty principle which showed that, the more you know about one of a pair of variables, the less accurately you can understand the other." This concept was not expanded at that time. The following example exemplifies that her concept of Heisenberg uncertainty principle improved later: "working to reconcile the concepts of orbiting electrons with Maxwell's theory, others like Heisenberg and Schrödinger, went even further in saying it was impossible to determine just where an electron was, not because we lacked the information concerning the location of the electron, but because any individual electron didn't have a location at

all! ...Heisenberg uncertainty principle, which explains problems of precision when dealing with two different pairs of variables ...the uncertainty principle dictates that, the more you know about a particle's velocity, the less certain you can be of its position, and vice versa."

The reviewers did not give her any comments or suggestions but asked some questions that were useful for her to clarify some concepts further. For example one of them asked "if total energy is the constant, isn't the phase shifting and growth of unique distinctions just the result of countervailing balances (a form of symmetry) throughout the universe? Applying the terms symmetry just seems to isolate something specific into pairs (or quantifiable bits)." In the final essay she clarified these concepts: "as the symmetry between forces breaks and as forces become distinct from one another, an enormous amount of energy is released. This breaking of symmetry between forces is referred to as a phase transition, ...depending on temperature...It is just a scenario, breaking of the total symmetry of the earliest phase of the universe which is believed to be responsible for the expansion, or inflation of our universe. ... (See Appendix A: EW-2 for next two paragraphs for more explanation).

The above analysis showed that her concepts about the course materials were improved using the method of course dossier. First of all writing critiques helped her to pick up and clarify the concepts every week during the semester. Secondly, different entries helped her to re-examine the facts again and again and improved her conceptual understanding of general physics and the universe. Although there were no comments from the reviewers nonetheless their questioning gave her a new way to think about the subject matter in writing the essay. Overall this method was useful for her to understand

the basic concepts of physics and fulfilled her interest to understand the structure and origin of the universe.

Case JH: Early in the course his concept writings were more descriptive than conceptual. Later on, he picked up some important concepts, which were covered in the class. In the fifth week he talked about the discovery of the electron and tried to explain its importance in the field of physics. Because he thought this discovery gave a new way to the scientific community to think about the nature of light. He wrote "when Thompson made such a discovery even he was incredulous of the implications claiming that he had to repeat the experiment several times in order to make sure what he had found was not a mistake. This was followed by an experiment performed by Lenard who created a similar circuit system to that of Maxwell's, leaving a gap between the metallic plates connected to the complete circuit. This experiment would prove to be incredibly informant as he found that the electrons ability of the light to escape one surface and go to another did not depend on the intensity of the light pointed at them but instead the color of the light". (See Appendix A: JH-1for more quotes)

The comments from the reviewers were very helpful. In the fifth entry one of the reviewers suggested; "it would be beneficial to the paper to have a brief conclusion paragraph. The conclusion paragraph would include what the purpose of the paper is and what are the overall findings." (For more comments see Appendix A: JH-2). This comment helped him present a very good conclusion, which was absent in the fourth entry of the draft (see Appendix A: JH-3 for conclusion).

His depth of understanding is also determined by his explanation about the comparison between quantum physics and cosmology. For example: “quantum physics looks at the every particle that make up materials; particles so minuscule that the laws of physics we apply to our own world can no longer be useful. These studies are used to give hints as to how these forces interact with one another and how this is related to the Grand Unified Theory. Cosmology is the opposite looking at a macro level and studying the traces and abnormalities that this colossal explosion left behind.”

Moreover some important questions came to his mind that helped him to expand his thought further. For example in the ninth critique he asked “to me one of the biggest difficulties is to imagine what all the forces were like when they were united as the explosion began?” In the final essay he explained this point as “the grand unified theory involves particle physics as it claims that at some point there was symmetry between the known forces electromagnetic, strong nuclear and weak nuclear. These forces were united by the extreme heat existed at the very beginning. The only force that is missing and continues to be a mystery as to how it is related in a quantum sense is the gravitational force.”

In conclusion, his thinking levels about basic ideas of physics improved using the course dossier method. During the course, the concept writing helped him to pick up the actual thought behind physics or physical laws. At the beginning of the semester it was hard for him to find them. Later in the course his concepts developed, because concept writing motivated him to explain the basic ideas that he discovered from the lectures in every week. So it was possible for him to link one theory to other and to have a complete scenario of the course materials at the end of the course. At the time of the critique

writings, he did not have a good understanding of some points. Later reviewing the comments on his critiques from the reviewers helped him to clarify concepts in the draft and in the final essay. In the draft he did not write anything as a conclusion. The reviewer's suggestion on his draft gave him the idea to write a very good conclusion in the final essay.

In his course dossier, he made a comparison between the important theories or concepts in a logical manner. This comparison helped him to explain the importance of discoveries in physics to understand the universe conceptually. Asking more questions produced more answers to the mind. He brought up some questions in his critiques that inspired him in further writings and improved his thinking level. Therefore this method helped him to understand the basic concepts behind physics and physical laws or theories. His final grade was B^+ partly because he missed four critiques.

Case JL: This student's major was Journalism. His course dossier showed that he explained some concepts well during the semester but most of the critique writings were written in a manner of summarizing the facts covered in the class. In his critiques he brought up some conceptual questions. For an example in his eighth critique he asked "the textbook says there are approximately 100 billion galaxies in the visible universe. Do scientists believe that the entire universe is still visible to us, or that the further edges are beyond our sight?" He tried to find out the answer of that question in his final essay as "there is thought to be anywhere from 100-400 billion stars in the Milky Way and somewhere between the same number of galaxies in the visible universe in terms of space exploration, the distances between our solar system and the next closest, Alpha Centauri

is 4.4 light years away... The only reasonable method to travel between the stars would be developed a way of crossing the distances at speeds far greater than that of light."

The reviewers' comments were very helpful for him in writing the final essay. His statement in the second entry exemplify that "it was interesting that to read the comments ...and I quickly understood that it was very difficult for them to understand what I was writing about without having been given the context. This is definitely I need to work on for my overview. I need to remember to couch everything I say in context and to give background information on every concept ..." (See Appendix A: JL-1 for another statement). Also comparing his critiques with the final essay showed that his understanding of the concepts had really improved when he wrote the final essay. For example in the eleventh critique he wrote about dark matter: "scientists believe that only about five percent of matter is the visible sort that makes up the galaxies, stars and planets. The rest of the universe is composed of dark matter and dark energy... If scientists are correct that means that most of what exists in the universe remains completely unknown to us." (The reviewer comment was: "if it is true only see 5% of all the matter in the universe, then what does the other matter do?"). In his final essay he explained this part as "what is the most surprising aspects of all this that if the current calculations are correct dark matter and dark energy make up about 95 per cent of everything contained in the universe. This means that everything we see, the planets, stars and galaxies combined only make up about 5 percent of all the stuff that exists." (See Appendix A: JL-2 for next paragraph).

The concepts, which were not explained well in the critiques, were clarified very clearly in the draft. For example in the first critique he wrote about neutrinos "by arming

the class with some basic information, such as the fact that neutrinos are thought to be mass less and rarely interact with matter enabled us to rapidly determined expansion for the early arrival of neutrinos". In the draft he explained this part more clearly: "what is particularly interesting about neutrinos is that there trillions of them passing through our bodies every second and yet we never notice them....because they don't interact with other particles very much. Neutrinos also do not carry electric charges...It's for these reasons that though there are trillions of neutrinos passing through my body ...they are extremely unlikely to interact with any of my particles." (See Appendix A: JL-3 for another example).

The above analysis showed that his understanding of concepts really improved through use of the course dossier method because writing the critiques helped him to review the material and to find the missing parts. As he said "rereading my critiques really helped me understand how many theories and concepts I wasn't able to fully understand, and which ones I felt the most drawn to" (2^{nd} entry). The reviewers did not give him good comments because in his critiques the concepts were not explained clearly. So it was hard for the reviewers' to understand everything and it was not possible for them to give useful comments for him. Nonetheless the reviewers' comments helped him to write a better essay. The reviewers' comments in the fifth entry exemplify that his concepts really improved afterwards: "I thought your essay really interesting and I feel like I learned a lot. It was a lot easier to understand than your critiques and it explained things really simply" (See Appendix A: JL-4 for another comment).His final grade is A^{+}. It implies that overall the course dossier method was helpful for him to understand the

basic concepts of general physics because at end of the semester it gave him the opportunity to review the whole material again and again.

Case KC: Up to the sixth week of the semester, he identified the key concepts from the lectures presented in the class, but couldn't explain them in a logical manner. For an example in the second week he wrote about the law of inertia, but did not understand it properly. His own words "some things (inertia) are harder to understand though. I spent two hours reading about it trying to figure out it." But in the final essay it showed that his concept about inertia became clear. He pointed out that Galileo used "the idea of a zero friction plane in which an object would continue moving in the same direction at its current speed unless acted upon by an outside force" (See more example in the Appendix A: KC-1).

From the seventh week, his explanations of concepts were given in a logical manner. For example he visualized the CMBR (Cosmic Microwave Background Radiation) and expansion of the universe as "for some reason I think of the CMBR like pouring soda into a glass. The carbonated water starts bubbling rapidly at first but after a few second it gets slower and until only a few bubbles at a time are surfacing. I wonder if it would be a better analogy if the glass you were pouring it into was expanding like the universe is." He also made a comparison between the Doppler effect of sound wave with the light wave coming from the distant galaxies-"the fact that galaxies that are farther away from us seem to be moving faster than those that are closer could be a Doppler effect of sorts". So it was possible for him to relate the physical laws with one another because this course engaged him to identify the relation between them.

Moreover, a lot of questions came to his mind during writing his critique assignments, as an example "I started thinking at some point (Schrödinger's cat thought experiment) if the electron can be a wave and a particle at the same time can the universe simultaneously exist and not exist? What caused the universe to suddenly exist?" Also based on the reviewers' comments on the first entry and after discussing with them, some questions strike him which were found in the third entry in his free writing -"if the galaxies had formed and there was a little more dark matter available would all the galaxy clusters be too tight and the night sky be too bright?" These types of questions are significant as those give him a way of thinking to go ahead for further writings.

Therefore, early in the semester it was hard for him to explain the concepts behind physics, but from the middle of the semester it was easier, because the concept writings helped him to improve his understanding of the subject matter day by day. Also comparing his critiques and the final essay it showed that the concepts were developed because the reviewers' comments gave him an opportunity to rethink the points, which were not explained well. As he said, "I am asking a lot of questions in this free writing (2^{nd} entry) may be its time I started answering some of them. I try not to fit everything together (in draft or final essay) but to make it fit like a puzzle or something." His final grade was an A^{+}. Therefore, by using the course dossier method his concepts were improved in every entry, because he had a chance to judge his writings and thinking again and again, using the reviewers' comments or by own perceptions.

Case LGG: This student's major was psychology. Her course dossier showed that her earlier critique writings during the semester were more descriptive that conceptual. In the third critique she talked about the physical laws related to planets' motions, but did not

understand the concepts behind these laws as she asked "how was Newton able to discover gravity and with it explain the motion of planets?" Her explanation of wave-particle duality of light and spectral lines exemplify that her concepts improved later on. In the fifth critique in which she wrote "we know that light particles can behave like waves, emit radiation, are electromagnetic and are called photons. Now, what we need to understand is that, depending on the wavelength, these particles are going to produce a different radiation (and different colors) that is going to be shown lines." (See Appendix: LGG-1 for more quotes).

In every critique, she asked many questions which were important for her because those motivated her to find new things which were covered in the next classes. As an example in the sixth critique she asked "are atoms only made of these three/four particles? And if they're more, where would they fit in the model of the atom? How do they travel in the atom? How do we know they exist? What are electrons and protons and neutrons made of?" Later on in the seventh critique she discusses her discovery of some answers: "the week before we had only seen how protons, neutrons place themselves in the atom, but this week, we have learned that there are more particles that compose this atom." (See Appendix A: LGG-2 for more questions).

The reviewers' gave very short comments on her critiques and also on the draft, but those were helpful for her in writing the final essay. She said "I have learned so much about the universe (from this course) and I am so glad to be able to discuss about it on this type of paper. It just confirm that I have understood most of the concepts and my friend's reviews have helped me to be able to better understand about what I've wrote."

It was possible for her to get a grade 'A' because the course dossier method gave her a way to review the concepts again. Therefore, her overall concepts about the course materials were improved using this method, because every week critique writing inspired her to keep on reading and forced her to discover the actual concepts behind the subject matter. The questions she asked in the critiques every week gave her an opportunity to understand the new concepts presented in the course materials. Moreover, the reviewers' comments were helpful in getting her to re-examine her critiques and the draft of the essay.

Case MF: Her major was studio art. Earlier in the course this student's critique writings were just summaries of the topics which were covered in the class. For example in the second week she referred to the first law of motion as "last week we went into the first laws of motion and how monumental it was to science. It confirmed earth motion as well as heliocentric system." She did not critically analyse the first law or how did it explained the earth's motion. Her concepts were improving as the course went on which was shown in her later critiques. In the ninth week she explained the grand unification and super-symmetry in a clear manner: "at the beginning, there was a grand unification of all quarks, leptons, and major forces. There was great symmetry within everything which means that forces that had different strengths become merged with the same strength and corresponding particles lose their separate identity. As everything calmed and developed, this super-symmetry was slowly broken. Matter was much hotter and denser, but as it cooled, its form and properties changed, going through various phases. This can be compared to transition of water from liquid to solid, to steam (gaseous state). Matter passed through succeeding phases of transitions as temperatures lowered until particles

such as electrons, neutrons, protons, photons and all that we know of today were created." (See Appendix A: MF-1for more quotes).

Her views on science also changed after doing the concept writings. As she said in the second entry "I think the scientific framework needs to adjust its philosophy to take in intuitive thought", while at the very beginning of the course her thought about the science was "I admit that my initial ideas about this introduction to physics class would consists of technical formulas, equations and basic theories. I even had some anxiety about the possible math we would be getting into."

By comparing the final essay and the draft overview it showed that her concepts were further improved. In the final essay, especially the introductory part (see Appendix A: MF-2) was written better than the draft of the essay. In this part she brought up all the themes, which were produced in the third entry for writing the essay. But those were not written clearly in the draft overview. Also she wrote a very good conclusion (See Appendix A: MF-3) in the final essay, which was absent in the draft. All of this occurred because the comments from the reviewers helped her to reorganize the introduction part and produce a good conclusion. For an example, one of the commentators advised her- "don't forget to restate your thesis and all your main arguments in the conclusion." (See Appendix A: MF-4 for more comments).

Therefore, assessing her course dossier it was found that her mental set up about science was changed after finishing this course, because this course gave a complete scenario of philosophy of science, a relationship between them, a successive development of science and the concepts behind physical laws or theories which build up the universe.

She said “to truly understand the study the nature of science, we need focus our attention to its course of development, societal functions as well as the processes of thought it produces.” Her basic concepts were also improved because every week concept writings forced her to find out the actual thought behind the course materials i.e. physics. Not only the concept writings but also the reviewers’ comments helped her to rethink or reorganize the overview and to present a better final essay. Overall, her thinking level about science was improved using this method and she had a good grade A^-.

Case RW: In her earlier critiques the concepts were not explained well. For example in the third critique she wrote “in keeping with the observational approach to planetary science, Galileo used sophisticated telescopes (that he himself constructed) ....He developed the law of inertia and used observations on earth to defend this principle through the example of a moving particle along a frictionless plane.” Later critiques were written better. In her fifth critique she explained the notion of electron as a particle and wave both: “the radical notion of electron is introduced and experiments with photoelectrons are conducted by Lenard, who discovered that the strength of the energy of an electron emitted by light depends not on its intensity but its color, and that shorter wavelengths caused electrons to be ejected with more energy. Einstein elaborated on these results and discovered the ‘photoelectric effect’. With Plank’s radiation law...he declares that light is localized in discrete small units called photons. ...His ideas did explain the findings from Lenard’s experiment and eventually provided the foundation for a new theory of physics based on the idea that electrons could possess both wave and particle-like properties.” (See Appendix A: RW-1 for another concept)

The concepts, which were not explained clearly during the semester, were written better in the final essay. In her tenth critique, she wrote "when the universe was 10^{-35} seconds old it was entirely composed of gauge boson radiation created by the splitting and recombining of particle-antiparticle pairs." In the final essay she explained this part in detail; "the asymmetry production of particles and antiparticles in the very early universe is also created what the seeds of matter itself. At around 10^{-35} seconds after the big bang, the universe was entirely composed of gauge boson radiation created by the splitting and recombining of particle-antiparticle pairs. When particles in contact with their antiparticles pair, they annihilate each other and produce radiation, thus explaining radioactive plasma state of the universe of the time. Although most of what the universe produced at its earliest stage was this auto annihilating particle-antiparticle pairs, about one extra particle in a billion pairs was produced and these extra, asymmetric particles are what formed the basis of all the matter in the universe today from atoms to galaxies."

Her reviewers asked some questions after reading her critiques, which were helpful for her to expand the concepts further. In her ninth critique one of the reviewers asked "interesting decrease in symmetry, can you expand if you wish?" In the final easy she expanded this part as "the symmetry that characterized the universe at its earliest stage implies that a break (or several breaks) in that very symmetry had to have occurred in order for it to evolve to its current state. As the universe aged, cooled down, and spread out, it did in fact go through a series of phase transitions, successive spontaneous symmetry breaks that caused increasing decrease in symmetry (decrease in symmetry) between the fundamental forces of nature as well as increasing matter asymmetry as distinct particles became identifiable." (See Appendix A: RW-2 for another comment).

Her final grade was A^+. It implied that her concepts really improved using the course dossier method. Comparing her earlier critiques with later critiques showed that her explanations about the concepts were improved. Also some concepts, which were not clarified during the semester, were explained very clearly in the final essay. Moreover the reviewers' comments helped her in explaining the things further in detail. Her written statement given after the course also exemplify that this learning tool was very useful for her to gain a through concepts of the materials of the course: "although the weekly assignments really did help me to stay on top of all the readings to formulate the concepts ...as the course progressed, the course dossier was an amazing tool for learning in that it forced me to re-evaluate my knowledge of the concepts throughout the course. The dossier plus final paper also allowed me to go back to the concepts more detail string them together in a way that permitted me to look at the bigger picture such a thorough understanding of the material without this time consuming but extremely useful exercise."

3.4 Data Analysis of Non-Interviewed Science Students' Writing Products

Case DB: His course dossier showed that up to the fourth critique he just picked up the basic concepts from the course materials rather than explaining the physical phenomenon. For example in his third critique he wrote about the spherical harmonics as "the spherical harmonics form a complete set for their space is all right but it's rather hard to visualize these functions." This sentence is very unclear to understand what he wanted to say. Later on in the sixth critique his explanation about motion of electrons was written in a clear manner: "if we consider a single electron in relative motion to an observer then obviously we have an electric field which varies in time and a magnetic

field is produced. ...the total electric field is in fact the superposition of the time varying electric fields due to the individual electrons in motion-which make up the current" which exemplified that his concepts were improved.

Some concepts, which he did not explain well during the semester, were clarified in detail in the final essay. For example in the seventh critique he wrote "this electromagnetic wave (E & M wave equation) has the same properties as light..." In his final essay he explained this part clearly: "these equations (Maxwell's equations) tell us all there is to know about how charged particles interact with each other. It happens that Maxwell's equations say we can have a disturbance which is made up of changing electric and magnetic fields and that this wave moves at the speed of light."

The above discussion showed that this student's concepts improved using the course dossier method. Every week critique writings developed the physical concepts behind the mathematics as he said "when we studied Green's facts in PHYS 336, the only physical meaning of $\Psi(x) = \int G(x,\xi)F(\xi)d\xi$I knew was that G represented the 'reaction of $\boldsymbol{\Psi}$ due to the force F'-which I didn't quite grasp. Your (professor) wording of its physical significance together with the analogy with Huygens principle for waves has really improved my understanding of Green's facts. In fact, now I can see the two interpretations are essentially the same!"(1st entry). Over all his understanding of the concepts changed in a major way because of the course dossier method (See Appendix A: DB-1 for his own comment).

Case GM: This student's course dossier showed that, in his earlier critiques he described the mathematical formulations rather than explaining the physical

phenomenon. In his later critiques he brought up some physical facts about electricity and magnetism but not written in a conceptual manner. His final essay showed that his understandings of the concepts were improved. The concepts, which were not explained well in the critiques, were explained very clearly in the final essay. For example in his seventh critique he wrote "the concepts of introducing a plane wave travelling in one specific direction has an interesting correlation with Maxwell's development of the wave nature of each magnetic field and electric field component perpendicular to the direction of propagation. This relation can be used as a stepping stone for understanding why light is an electromagnetic wave." In the final essay he explained this part in a clear manner: "Maxwell's equations...lead...light waves are actually electromagnetic waves. By taking the waves travelling in empty space and considering that the waves are plane waves, the two Maxwell's equations involving divergence become equal to 0. This allows one to separate of the other two wave equations into four distinct wave equations. From ones knowledge of the wave equation it becomes apparent that the velocity of propagation is that of the speed of light" (see Appendix A: GM-1 for rest of the part).

The reviewers' comments were helpful in getting him to explain the concepts in more detail. One reviewer's comment about his second critique was "try to find the physical (more intensifying) meaning" where he wrote "the Green's is built in such a manner...which will account for the boundary conditions. Since boundary conditions can be expressed as different functions depending upon which coordinate system is used..." In the final essay he explained the usefulness of Green's function in physical system: "the Green's function ...transfer a non-homogeneous differential equation into a homogeneous one...the actual way by which the differential equation becomes homogeneous with...the

use of delta function to replace the non-homogeneity...effectively produce a discontinuity in the derivative of Green's function. The continuity of Green's function and its' discontinuity in the first derivative allows one to solve for any undetermined coefficient in the solution of non-homogeneous differential equation with boundary conditions."

Overall the course dossier method helped him to improve his understanding of the concepts of electromagnetism. Weekly critique writing gave him a way to find out the concepts behind physics. Different entries after the semester helped him to find out the missing parts and gave him an opportunity to review the materials again. The reviewers' comments were useful to help him to explain the concepts further in writing the final essay. In this way his depth of understanding developed by using this learning tool.

Case GW: This student's critiques showed that he really found the very important concepts from the course electromagnetism and explained them in a clear manner. For an example in his eighth critique he talked about the conservation of the electric potential field and wrote "the existence of a scalar potential function in electrostatics is a direct consequence of the properties of the electric field, namely the conservation character of the field. More generally, any conservative field has a potential function and we expect that conservative field has a potential function and we expect that the conservative fields will have a similar mathematical form and all the mathematical tools developed up to now for the electrostatic electric field should apply equally well to any conservative field."

Early in the semester some concepts were not clarified, later on he explained those concepts. For example in his fourth critique he wrote "the use of Green's function in

solving electrostatic problems is allowed because the electric vector field obeys the principle of superposition." He did not explain this concept in that critique (one of the reviewers also suggested him to explain that part). In his eighth critique he explained that "for a localized charge distribution, we also expect to have a certain amount of symmetry. To obtain a measure of the symmetry of a problem we use the multi-pole expansion which is basically the expansion of green's function in terms of spherical harmonics. If we split the expansion in a source part ($r^{'}$) and field part (r), and we define the multi-pole moment as the source part (constant for each l and m) we can express the potential as a sum of multi-pole moments. This multi-pole moment are related to the geometrical distribution of the discrete charges" (See Appendix A: GW-1 for rest of the part).

The reviewers' comments also helped him to expand the concepts further. In his ninth critique one of the reviewers suggested "you could explain more clearly what the Maxwell's equations" in understanding the concepts on his writing part "change in charge density is related to the differential form of Gauss's law, a more symmetrical and complete set of Maxwell's equations is obtained and the total dependence of electric and magnetic fields emerges." In the final essay he explained the Maxwell's equations in detail: "the set of Maxwell's equations establishes the relation between electricity and magnetism. We have the sources of the electric and magnetic fields as charges and currents. But these equations also predict the electric and magnetic fields in charge free regions where the sources are the fields themselves. By manipulating the equations, we obtain a wave equation for both the electric and magnetic fields. The constant of proportionality in both equations is the velocity of light. This leads to the amazing result

that the light is an electromagnetic wave propagation" (See Appendix A: GW-2 for rest of the part).

The above analysis showed that his concepts of understanding of electrodynamics really improved by using the course dossier method. This method forced him to read and to think about the concepts behind physics. The reviewers' comments were also useful as those gave him guidance to write the final essay. The overall course dossier improved his critical thinking in a clear manner. His written statement after the course also exemplify that: "I feel the course dossier is really helpful in understanding the material introduced ...The post summary (the critiques) and the post -post summary (the course dossier) ...allowed us to think on what had been presented in a critical manner and they made us translate our thoughts to paper in a clear manner." He also thought "it is definitely one course that I will remember and not only for the theory of E& M but a course that taught me how to think."

3.5 Results and Discussions

This section is the overview of the previous sections (3.2, 3.3, and 3.4). Table 3 is the summary of the analyzed data of the writing products of the four interviewed (non-science) students; Table 4 is the summary of the analyzed data (interviewed students) based on interviews; Table 5 is an overview of the analyzed data of the non-interviewed (non-science) students and the Table 7 is the summary of the analyzed data of three non-interviewed (science) students. This section will discuss the ways the critique writings improved the students' understanding of the subject matters during the semester by comparing the cases, the ways the reviewers' comments were useful for students in

analyzing the subject matters further. Moreover, how this method changed the students' views on physics will also be discussed.

Table 3. A Summary of the Analyzed data of Writing Products (Interviewed Students)

Case	Earlier Critiques	Later Critiques	Reviewers' Comments	Final Essay	Final Grade
JS	Found the important concepts, explanations were unclear.	Explanations of the concepts were improved.	Very useful (did not use all the comments because lack of time).	Much better than the critiques.	A
TS	Discovered the very important concepts, but the explanations were not clear.	The concepts writings were improved.	Very useful to find the missing parts. (did not use all the comments)	Explanations were much better than the critiques.	A$^-$
DC	Summarizatio n of the topics.	Explained in detail. (missed five critiques).	Useful to find out the themes.	Better than earlier writings.	B$^-$
LL	The writings were not related to the course.	Missed 5 critiques.	Did not use the reviewers' suggestions.	Did not follow the instructions at all.	F

From Table 3, we see that the students JS and TS tried to follow the instructions of the method properly. They did not miss any critiques during the semester. For JS, the reviewers' comments were very useful, but he claimed that it was not possible for him to use them because of lack of time. The reviewers' comments were also very useful for TS to find out the themes although he did not use all the comments. DC missed five critiques. So it was not possible for the reviewers' to give him many comments on the critiques, nonetheless they were helpful to find out the themes for him in writing the final essay. Student LL did not follow the method at all. He also missed five critiques. Although very short but good suggestions came from the reviewers, he did not use them. JS and TS did not miss any of the critiques so critique writings helped them in many

ways. By comparing their critiques (section 3.2) we see that their concepts improved during the semester and after the semester.

In Table 4 we see that the student JS found that looking back at the materials (critiques) again after the course helped him to re-examine the concepts again which indicates that he engaged with hermeneutical movement according to Gadamer (2004). This process helped him to think about the materials of the text in a clear manner. In the same way the student TS approached the critiques in engaging with the concepts and opened up his views on science. For DC the critiques were challenging because he found many concepts to understand and did not try to explain those concepts in a critical manner. So in writing the critiques he was just summarizing or paraphrasing the facts from the book in his own words. The student LL did not bring up any physical consequences in his writings.

Table 4. A Summary of the Analyzed Data of Interview Products

Research Questions	Case	Students' Approach
In what way writing the critique was helpful to improve the students' understanding of the subject matters?	JS	The critique writings helped him to think about the course materials. Looking back at the critiques was very significant because he had to go back to the course materials. He felt overwhelmed because he re-examined the concepts again, which gave him a very clear path in writing the final essay.
	TS	He thought the critiques opened up his eyes about science because he found common themes after reviewing the critiques.
	DC	The critiques were challenging for him, because there were many concepts to understand and did not try to explain those concepts in a critical manner. In writing the critiques he was just summarizing or paraphrasing the facts from the book in his own words.
	LL	Did not bring up physical things in his critiques writings, so his critiques were not clear to understand the subject matter.
In what way were the reviewers' comments useful for students in analyzing the subject matters?	JS	The reviewers' comments were very helpful in explaining the concepts better because they found mistakes but he was not able to use all of those comments in explaining the concepts because of lack of time.
	TS	The reviewers' comments were very helpful because of their analysis of the critiques.
	DC	When he was reading the reviewers' comments he discovered many questions about science which motivated him to write something better.
	LL	His reviewers' didn't give him meaningful comments because they were very busy at that time.
How helpful was the course dossier method to improve the students' general understanding of concepts behind physics?	JS	It was really an interesting process for him and a very different learning method.
	TS	The overall course dossier opened up his eyes and his mind about physics because this method caused him to think about concepts rather than memorizing facts and the whole course gave him a better perception about physics.
	DC	This learning method is a way to review the concepts and to learn something new by going over the course materials again.

	LL	This method is really rare in educational system and can help the students' to think deeper and can help make links to real life.
How has this method changed the students' views on physics?	JS	This course has changed his perception about science, because before he thought science is just straightforward. Now he realized science is two steps forward and one step backward.
	TS	His perception about physics really changed after the course because before taking this course he thought physics is basically related to speed, velocity or force; after the course he realized that physics is everything around us.
	DC	No indication
	LL	No indication

All four interviewed people took the course dossier method positively. JS thought this method helped him to review the course materials and to understand the concepts better, because it was really an interesting process for him and a very different learning method rather than the traditional learning method. For TS, he also thought that this method enabled him to approach the course in a very different way, because this method caused him to think about the concepts rather than memorizing the facts and the whole course gave him a better perception about physics. Student DC thought this learning method is a way to review the concepts and to learn something new by going over the course materials again, because the critiques were the main issue of the course dossier method. Although LL did not follow the method at all nonetheless he realized that the method is very useful for the student because it can help the students' to think more deeply and can help make links to real life. He also felt that this method is really rare in the educational system.

The above results revealed that the two students (JS & TS) followed the method properly except in using the reviewers' comments as the lack of time for the case JS and for the case of TS, he only used the reviewers' comments for the themes. JS got an A as a final grade and TS got an A$^-$. Therefore it would possible for JS and TS to have a higher grade if they would follow the reviewers' comments properly. Nonetheless their perception of physics really changed (see Table 4) by using the course dossier method because they properly followed the other steps of the method during the course and after the course. They tried to construct their knowledge as an active learner, because critique writings helped them to interpret the text by their own using hermeneutical movement. Every step of the course dossier engaged them with the materials of the course with in a

manner of hermeneutical circle, because they reviewed the materials again and again. This process helped them to find out the misconceptions and helped them to reach a level of insightful concepts (See Table 4). On the other hand, DC got a B^- grade. He missed five critiques and was more of a passive learner, because he did not try to interpret the text on his own, just summarizing the facts in writing the critiques. He also did not use the reviewers' comments properly. Those impacted on his final grade negatively. There was no indication about a change of his views about physics for this course (Table 4). LL is a very different case from the others. His course dossier was not related to the course material. He did not follow the method at all, did not take the course seriously, so he received a failing grade.

Table 5. A Summary of the Analyzed Data of Writing Products (Non-Interviewed Non-Science Students)

Case	Earlier Critiques	Later Critiques	Usefulness of Reviewers' Comments	Final Essay	Changed in Views of Physics or Students' Comments
AR	Summaries of the topics.	Pick out very important concepts rather than explained in depth.	Very useful for finding the missing parts in the critiques.	Explanations of the concepts were much better than the critiques.	"I have to say that this has been an incredible experience. It has opened my mind to many of the inner working of the universe."
AV	Pick up concepts, but explanations were not clear.	Make a connection between the ideas found in his earlier critiques with new thoughts discovered later on in the course.	Helpful for identifying the missing ideas in pre-writings.	Explanations of the concepts were better than critiques.	"Science becomes more of a continual process of improving human knowledge by constantly testing it and verifying hypotheses as new means of observation and experimentation are made available."
BDS	Picked up very basic concepts, explanations were somewhat unclear.	More details than earlier.	Very useful for further writings.	Concepts were clearer than in critiques.	"Prior to this course, I had thought that this (Quantum Mechanics) strictly opposed a classical, mechanical and deterministic view of reality... I now understand the uncertainty principle and quantum mechanics to be a predictive theory rather than a descriptive one."
CR	More descriptive rather than conceptual.	More conceptual than earlier critiques.	Very useful for explaining the concepts.	More conceptual than in the critiques.	"I am grateful for having taken this class as it opened my mind to scientific approaches to things."
EW	More descriptive than conceptual.	Explained better of the concept than earlier	Helpful to clarify the concepts further.	Much better than critiques.	

		critiques.			
JH	More descriptive than conceptual.	Better than earlier critiques.	Helpful in writing the final essay.	Much better than critiques (critique writings were very helpful in writing the final essay).	
JL	Summarizing the important topics.	More descriptive than conceptual.	Very helpful to identify the missing concepts.	Very well written compared to the critiques.	"Rereading my critiques really helped me understand was how many theories and concepts I wasn't able to fully understand, and which ones I felt the most drawn to."
KC	Picked the key concepts, explanations were not clear.	Explanations of the concepts were improved.	Very helpful for further writings.	Explanations were clearer than in the critiques.	
LGG	More descriptive than conceptual.	Improved explanation of the concepts.	Very helpful to understand something.	Much better than critiques.	"It just confirm that I have understood most of the concepts and my friend's reviews have helped me to be able to better understand about what I've wrote."
MF	Summarizations of the topics.	More clear than earlier critiques.	Very helpful to reorganize the final essay.	Concepts were much better than critiques.	"My initial ideas... to physics... consists of technical formulas, equations and basic theories" Later on, "I think the scientific framework needs to adjust its philosophy to take in intuitive thought."
RW	Explanations of the concepts were unclear.	Explanations of the concepts were improved.	Helpful to expand the thought further.	Very well written better than the critiques.	"The course dossier was an amazing tool for learning ... it forced me to re-evaluate my knowledge of the concepts ... also allowed me to go back to the concepts more detail string them together."

Table 5 shows that for students AV, BDS, CR, EW, JH, KC, LGG, MF, and RW, their understanding of the concepts improved in the same way during the semester. These students did not explain the concepts in the earlier critiques in a clear manner but the explanations improved in the later critiques (section 3.3). The student AR missed 6 critiques (Table 6), and during the semester his concepts did not improve significantly. The reviewers' comments for AR could have been very helpful for him to improve his understanding of the concepts and could have helped him to write a final essay in a critical manner. He lost marks in the critiques so that his final grade was B^-. JH also missed 4 critiques (Table 6) that affected his grade (B^+) although the reviewers' comments helped him to write a better final essay. On the other hand, for the case of JL, his understanding of the concepts did not improve during the semester, but in writing the final essay his understanding of the concepts were drastically improved (see section 3.4) by using the reviewers' comments, and this helped him to write a very good final essay. So that he got an A^+ (Table 6). Also, for the case of AV, BDS, CR, EW, KC, LGG, MF and RW, their reviewers' comments were also very helpful to identify for them to enhance their understanding of concepts as exhibited in the final essay. Reading Table 6 we see that AV, BDS, CR, KC and RW, received a final grade of A^+ and they did not missed any critique.

The students' comments found in Table 5 showed that their approach to science changed in writing the course dossier. See in particular the comments of AR and CR. Additionally AV, BDS and MF's comments show that their perceptions of physics changed with engaging this learning tool. Moreover, JL, LGG and RW's comments

indicate that the course dossier method helped them in learning physics concepts in a different way.

Table 6. Final Grades of Non-Interviewed Non-Science Students

Case	Final Grade
AR	B^- (Missed 6 critiques)
AV	A^+
BDS	A^+
CR	A^+
EW	Not enrolled in the course
JH	B^+ (Missed 4 critiques)
JL	A^+
KC	A^+
LGG	A
MF	A^- (Missed 1 critique)
RW	A^+

Table 7: Summary of the Analyzed Data of Writing Products (Non-Interviewed Science Students)

Case	Earlier Critiques	Later Critiques	Reviewers Comments	Final Essay	Changed in Concepts
DB	Finding the concepts rather than explained clearly.	Concepts were improved.	No indication how helpful the reviewers comments.	Much better than the critiques.	Understanding of the concepts changed in a major way.
GM	Described the mathematical formulations rather than explaining the physical phenomenon.	Brought up some physical facts but not written in a conceptual manner.	Very useful to find the physical meaning of the equations.	Understandings of the concepts were improved compared to the critiques.	
GW	Explained the concepts clearly.	Explained the concepts very clearly.	Helpful for further writings.	Understandings of the concepts were improved compared to the critiques.	"..the course dossier is really helpful in understanding the material ...The post summary (the critiques) and the post -post summary (the course dossier) ...allowed us to think on what had been presented in a critical manner and .. translate our thoughts ... in a clear manner." "..course that taught me how to think."

Table 7 shows that the science students' understanding of concepts also improved in the same way as those of non-science (interviewed and non-interviewed) students as discussed above. The tabulated summary (Table 7) of the analyzed data showed that DB and GW's understanding of concepts improved during the semester. For the case of GM his understanding of concepts improved but explanations were not clear in the later critiques, but with the aid of reviewers' comments his understanding of physical concepts improved further in writing the final essay. The reviewers were helpful for GW and for DB, no indications about how useful the reviewers' comments were. Overall the science students' understanding of concepts improved by using this learning tool as GW expressed that the course dossier really helped him in understanding the materials in a clear manner and taught him how to think. The science students' marks (Table 8) in the final essay are further support that this writing to learn method helped them to understand the concepts behind physics in a clear manner.

Table 8. Final Essay Mark of Non-Interviewed Science Students

Case	DB	GM	GW
Mark in the Final Essay (%)	80%	80%	100%

Overall discussion: The above results and discussion showed that all of the students' (non-science and science) understandings of physics concepts improved markedly by using the course dossier method as this method forced them to go back and to fro of the subjects matter again and again. This method engaged the students with the activities in a manner of hermeneutical movement (Gadamer, 2004). Most of the students' understanding of concepts of physics improved during the semester, because critique writing helped them to pick up the concepts and explained them in own words. Weekly critique writing helped them to bring up some questions in the class. These questions

motivated them to discover the new concepts. Moreover, earlier critique helped them to link the prior concepts with the new ideas. Rereading the critiques after the semester helped them to find out the misconceptions. Therefore, they became aware of their misconceptions. These misconceptions helped them to reinterpret the concepts in writing the final essay, because misconceptions are the starting point of hermeneutical circle (Gadamer, 2004) and that gave available routes to the students' in bridging the horizon of the text with their own horizon (Eger, 1992). Also this method helps the students' to engage with the hermeneutic disposition openness of mind and hermeneutic disposition awareness of misconceptions that gives the opportunity to find the new concepts.

For most of students, the reviewers' comments were helpful to construct their physical concepts. Some of the reviewers' asked many questions, some of them gave very good suggestions after reviewing the critiques and draft of the essay. In most cases we found (sections 3.2, 3.3, 3.4) this questioning helped the students to find the missing parts in their critiques and/or the draft essay. Knowledge of these missing parts led them to rethink the materials again intuitively. Moreover, the reviewers' suggestions gave them a clear path to organize in writing final the essay. The interaction with the reviewers is in line with Vygotsky's (1978) notion of social constructivism. According to Vygotsky's point of view the students can scaffold their intellectual knowledge to a higher level with the aid of other people like teachers or peers. The students who pay attention to the reviewers' comments could able to expand their understanding level that is ZPD (Vygotsky,1978).The students' who did not pay attention to the reviewers' comments (cases TS, DC, LL for example) in writing the final essay had lower final grades that mean those students' ZPD did not expanded. The course dossier method allowed the

students to structure and to restructure their conceptual knowledge in a clear manner with the help of peers. Therefore this method helped the students' to understand the concepts as an active learner rather than a passive acceptor (Wink & Putney, 2002).

The overall results and discussion showed that the course dossier method helped the students to improve their understanding of concepts-not only the non-science students' but also the science students'. This study should be helpful for science educators in designing their science courses for non-science students' and higher level science courses for regular science students'. Also this study gives the instructors to know how the students' can get rid their misconceptions and become an active learner.

Chapter 4

Conclusions

Writing-to-learn strategies have helped students to overcome their misconceptions. In particular, the writing-to-learn tool, course dossier method has been shown to help students understand the general concepts of physics. The purpose of this study was to investigate in what way writing the critique was helpful to improve the students' understanding of the subject matters? In what way were the reviewers' comments useful for students in analyzing the subject matters? How helpful was the course dossier method to improve the students' general understanding of concepts behind physics? How has this method changed the students' views on physics?

Both the humanities students' (see Table 4 & 5) and the science students' (see Table 7) understandings of general concepts of physics improved markedly by using the writing procedures of the course dossier method. This writing procedure helped the students to become aware of their misconceptions. They had the opportunity to use their preconceptions in post writings and got a way to link the prior concepts with the new ideas. This method helped them to interpret and reinterpret the concepts of the subject matters through the writing procedures, and helped them to expand their horizon to understand the subject matters in the manner of a hermeneutical circle. The investigations showed that weekly critique writing helped the students to find the concepts and rereading the critiques after the course helped them to become aware of their misconceptions. In this way, the critique writing helped the students to improve their understanding of the subject matter. Also, through these writing procedures, the students'

had the opportunities to ask questions themselves and to discover the answers of those questions by their own. Therefore, this method helped the students to open their mind to know something new that is the students engaged with hermeneutic dispositions. This type of engagement broadens the students' horizon and able to come closer to the horizon of the text and helps to get rid of misconceptions.

Moreover, the course dossier method helped the students to scaffold their understanding of the concepts to a higher level with help of the reviewers' suggestions in accord with Vygotsky's (1978) notion of social constructivism. This non-traditional writing method gave them a clear path to structure and restructure their concepts with the interaction with the reviewers' comments. The students' ZPD, that is their understanding levels or thinking skills expanded with the aid of peers. Therefore this method helped the students to understand the concepts as an active learner rather than a passive acceptor.

Some student's views on physics were also changed in using the course dossier method. For an example MF said "my initial ideas ... to physics... consists of technical formulas, equations and basic theories..." Later on, she thought that "I think the scientific framework needs to adjust its philosophy to take in intuitive thought."

Therefore this non-traditional writing-to-learn method helped the non-science students to understand the subject matter and also gave the science students a way to learn the concepts behind the mathematical equations.

I believe that this study:

1. would encourage non-science students to take science courses. One of the reviewers of JL said "after rereading this (draft of the final essay) I think I would have liked taking your class. Maybe next semester."
2. would give the non-science students' a way how to learn physics.
3. help students to expand their horizon and ZPD.
4. help the students to become an active learner.
5. help science educators in designing their courses.
6. help the instructors to know how the students can overcome their misconceptions to learn physics concepts.
7. help instructors in constructing their classroom environment.

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Appendices

Appendix A

AR-1: He mentioned "the first thing to understand about quantum mechanics is that nothing is certain. Everything you deal with in quantum mechanics is subject to probability. This is essential to understand because the simple fact is that it is impossible to figure out where anyone particle is at any one time. We can only describe the area where there is a high probability of finding a particle." He explained that positively charged protons in the nucleus of atoms do not fly apart because the strong nuclear force holds them together in the nucleus. In the same way electrons around the nucleus are not captured by the nucleus because leptons as a whole are not effected by the strong nuclear force. He also presented a good discussion about quarks and gluons. He stated "when quarks are near to each other, the gluon exerts a very little force on them. The more a quark attempts to move away, however, the greater the force the gluon exerts pulling it back in. The force that the gluon exerts will eventually overwhelm the quark and draw it back in. It is for this reason that quarks do not ever exist by themselves. Free quarks do not exist in nature." [Final essay]

AV-1: "I see a link between this concept (Schrodinger's wave mechanics and Heisenberg's uncertainty principle) and debating Bacon's scientific method of finding patterns in nature versus Newton's method of formulating hypotheses. In both cases, we will never have an ultimate picture of the universe so to speak, but in the latter case (fruitful theory); other can participate with peer review and working to falsify incorrect

hypotheses, helping to enlarge the picture, even if it can never be a complete one. This is the benefit of multiple viewpoints."

AV-2: Reviewer's Comment: "Newton's scientific method opens scientific investigation up to the possibility of approaching the scientific process to bias." [1st entry]

Student's statement: "By merely looking for the patterns within the observed data, Bacon missed the fact that our own patterns of thinking and biases will inevitably determine which patterns we identify! So Newton's method has the added benefit that by using falsifiable hypotheses." [2nd entry]

AV-3: "The Rogerian argument is significant to the scientific community because it allows the hypothesis of theory in question to be the real focus of discussion, and removes things like threats, biased language, and unnecessarily strong statements of opinion. Instead, the aim of the Rogerian Arguments is to demonstrate that the participants of a discussion understand one another, which increases the chances of successful communication, and that an atmosphere of trust is establish. Non-threading arguments are to the point, objectively-phrased, and contain complete and neutrally-worded analyses of both the position being put forward and that being disputed; they also focus on shared goals and values, and propose means of resolving for scientific the issue to the satisfaction of both sides. While scientific inquiry may always be able to accommodate all of these conditions, adopting this framework builds trust and enables communication. These are crucial factors for scientific work to be as efficient and objective as possible."

AV-4: The value of collaboration: "While free-writing I realized that many advances in science from the process of collaboration between scientists. Peer review is an essential component to many of the discoveries we have studied in the course, and the results are more objective and less biased when individuals are involved."

Benefits from errors: "Scientists discoveries are also often the results of past errors corrected evidence is presented or new technologies allow us to observe what was previously unknown to us. The notion of falsifiable theories is also extremely valuable, because without it our claims to knowledge would be much weaker. Scientists must be willing to risk being proven wrong in order for knowledge to advance."

Also wrote "science becomes more of a continual process of improving human knowledge by constantly testing it and verifying hypotheses as new means of observation and experimentation are made available."

BDS-1: "The Big Bang and inflation, for example, as speculated by Einstein nearly one hundred years ago, both suggested the release of large gravitational ripples across the universe-the ripples which would distort the entirety of space-time and slowly fade out of existence." [10^{th} critique]

BDS-2:"At the end of my last critique (sixth critique) I mentioned how quantum mechanics, to an extent, is a tool for exploring human experience in the physical world, as opposed to an underlying ultimate reality. Reading that a week later, I think my views have slightly changed on the subject matter and what we looked at this past week really emphasizes that. Specially, through the process of beta radiation decay and the inconsistency of energy between the value in the B nucleus (decayed nucleus) and

experiments showed that there was some missing value which was uncovered and was needed to properly balance the energy levels of a decaying electron. That this was inducted due to an absence of human observation shows, I think, the underlying truthfulness of these theories in the world."

BDS-3: Reviewer comment: "Your understanding of quantum mechanics demonstrates where old concepts of verification run into problems, will this alter how scientific questions are answered and how does this allow philosophy to reconnect with science?"

BDS-4: "We can now try to formulate a cohesive understanding of what the science of physics is, especially in regards to particles and galaxies. Sticking with our Aristotelian roots, we can do so through an understanding of its material and formal causes, its efficient causes and its final cause. Science as we've seen it, is comprised of thoughts, observations, evidence, data and analysis, and involves the process of applying abstracted, universal knowledge to particular events and phenomenon. .....Science therefore is the forward ebb of our knowledge horizon concerning a relative objective truth about the natural world around us. Particles and galaxies, despite being on the opposite spectrums of the macroscopic and microscopic scales, can be syncretically studied when looked at in such a fashion. After all, both areas are concerned with building new knowledge on the foundation of older theories and laws, and it is this search for ultimate truth from within the unknown and through the use of the scientific method that reconciles these two, otherwise quite distinct, realms of knowledge."

CR-1: "Newton's theory that light is particles, and Hook and Huygens's that light is waves. Young and Fresnel's double slit experiment was later seen as the crucial experiment that proved that light as waves."[5th critique]

CR-2: "There was also the demonstration of a positronium which is composed of both a positron and an electron which can occur for a short while before the occurrence of annihilation. This demonstrated the credible discovery that a proton was composed like an atom. This opens up the world of physics to a much greater search for understanding." [9th critique]

"Due to NGC3198 model done by Begeman, we can see that the rotational velocity of stars that they get further out from the center initially increases quietly quickly but then almost immediately flatters out and even slows as the edges of the galactic plane. This indicates a rather large amount of dark matter being present just outlying the center of the galaxy (or cluster or super cluster) and an encompassing sphere of dark matter around the system. These findings offer a near-concrete idea of dark matter's locale and function, but we still cannot pinpoint its make-up." [11th critique]

CR-3: "**An introduction of Physics**- This course helped students to achieve a comprehension of the universe through the eyes of physics. It covered the history of physics from early philosophy to our current understanding of the universe and its composition and behaviour. It shed light on the arduous experimentation and philosophising that has occurred for centuries within the minds of philosophers, scientists and physicists who have had the incredible gift of undying curiosity and perseverance to see through the mysterious ways of all things. The lectures sought to answer questions of:

how to conducts scientific experimentation; what is the best method for exploring scientific thought; how do theories evolve; and how does the quantum level relate to the macrocosm universe."

CR-4: Question- "As much as Aristotelians or Baconians would argue that they rely purely on observation without biased expectation, isn't there a more deeply ingrained idealism beneath observation with the expectation of discovering laws?" [5th critique]

Explanation: "While a Bconian or Aritotelian focuses purely on individual cases at hand, thinkers such as Galileo imagine theories to explain unobservable aspects of existence. Galileo visualized that a ball rolling on an infinite, flat, frictionless plane would never slow down or change speed. From this theory arose his law of inertia. Although inertia is not an absurd theory, and is now a law that is generally accepted, Galileo had no manner to determine that it was absolutely correct. There exists no flat plane that infinite, let alone frictionless. Thus arises a flaw of idealization in that there can be no real certainty for any theory if there is no direct experimental way to prove such a case." [Final essay]

DB-1: "In previous courses we would always begin magneto-statics with the Lorentz force law which tells us the force on a moving charge due to an external magnetic field. ...I found ...that the subject of magneto-statics should be taught without any reference to electric fields. In fact up until now I had the notion that electric field due to a 'stationary' charge would be greater than its electric field when it was in relative motion!"

DC-1: "We discussed the term omega which designates all matter and dark matter in the universe essentially everything. We looked at three models of universe where the

term omega was either lesser than one, or greater than one. Where the omega is lesser than one the universe is open and can expand forever. Where omega equals more than one the universe is close and expanding to a point where it reach its zenith and then collapse back on its self because of its mass." [11th critique]

EW-1: Next Paragraph- "The discovery of the universe's expansion led to a new understanding of how the early universe must have look. Gammow surmised that, as the universe is expanding, and thus, matter is further apart than it once was, the universe must also be cooling. Therefore, the early universe would have been very hot...even to allow for atoms, and consisting only of plasma. Gammow further predicted that there should be some sort of relic of this early, extremely hot universe. This prediction was confirmed by the discovery of Cosmic Microwave Background Radiation (CMBR), which is found throughout the universe." [8th critique]

Another Concept: "Similar to the way in which protons require the strong nuclear force to bind them within an atom, when it was discovered that protons are themselves made up of quarks, something else was required to explain how the quark managed to stay bound together. The problem was that, according to the classification scheme, the quark had to be weakly bound, but because they never escaped the nucleus, they also had to be tightly bound. The answer to this lay in the discovery of gluons, which are responsible for binding the quarks and which act like springs, reacting either weakly or strongly depending on whether they are being 'pulled' or not." [7th critique]

EW-2: Next Paragraphs- "This first phase transition also appears to be responsible for distinguishing gravity from the other forces- certainly a boon for us, as gravity is

needed to attract matter together to form stuff like stars and planets. But that's not the only way that breaking of symmetry... Even with gravity in the mix, matter still has to come into existence in order for gravity to make it lump into bigger structures, and symmetry breaking helps us there too, as does the seemingly chaotic violation of the conservation of energy law allowed by Heisenberg's uncertainty principle".

"In that early universe, when there was as yet no matter but only radiation in the form of gauge bosons, energy fluctuations occurring over very tiny periods of time allowed for energy to be 'borrowed' in order to create symmetry pairs of particles and antiparticles. Naturally, when paired together, particles and antiparticles. Almost immediately annihilate one another. This explains how the law of conservation of energy could be violated in the creation of particles-anti particles pairs, as the annihilation happened so quickly that the borrowed energy would be repaid in a short enough time-span to respect the framework outlined by Heisenberg. But, had there been a complete symmetry these particle-antiparticle pairs, the universe wouldn't be what it is today, a place filled with matter." [Final essay]

GM-1: Rest of the part-"Moreover, the fact that these are plane waves allows one to have no periodically changing longitudinal component for the vectors lying on the plane perpendicular to the direction of propagation. If one is to take account of non-empty mediums than the medium of propagation plays a crucial role in the characteristic of the observable quantities. The interactions between the medium and the electromagnetic waves for a given medium can be fully described as a function of permittivity and permeability. If one notes that for a non empty medium these describers are highly

dependent on frequency than one realizes that the dispersion of the electromagnetic waves is also highly dependent on frequency of the wave." [Final essay]

GW-1: Rest of the part- "The names of the different multi-poles are related to simple geometrical arrangements of the charge distributions and again relate the symmetry of the problem to the arrangement of the charge distribution. So an 'expansion' consisting of only one multi-pole implies a totally spherical symmetric problem (monopole) or a two charge arrangement (dipole) and so on. The terms after the first non vanishing multi-pole in an expansion depend on the frame of reference and they give a measure of the deviation from the particular symmetry involved. The frame of reference dependence means that for certain problems (pure monopoles and dipoles etc.) we can make them vanish with a correct selection of frame of reference." [8th critique]

GW-2: Rest of the part- "But the electric and magnetic field equations were deriver without reference to a medium and a wave in the classical sense needs a medium to propagate. The search for the ether was at is full height during the XIX century and it certainly got boosted by the predictions of light as an electromagnetic disturbance. ...If such medium existed it should have very special characteristics since it should be tenuous enough to allow for such a large speed of propagation and it should have strong restoring forces to account for the propagation of wave. ...The whole theory of radiation began here and apparently different phenomena could be explained in terms of electromagnetic waves. Light became a minuscule band in the broad spectrum of electromagnetic radiation." [Final essay]

JH-1: More Quotes- "Even though it (Einstein's photoelectric effect) goes against basic notions of reality and common sense, light is not a beam that is constantly shining on us but instead it is a variety of beams that heat us in intervals of time in such succession that they merely appear to be still." [5th critique]

"These particles (neutrinos) proved to be more elusive than the particles found in the nucleus, as they were greatly unstable." [7th critique]

"There is of course proof that (expansion theory) backs up these claims, such as the near uniformity of the cosmic microwave background radiation. The theory also accounts for the lumpiness in this phenomenon, because the universe was so miniscule at very beginning quantum fluctuations, which are known for happening in vacuum, would be more significant at this level. Thus when the expansion occurred the fluctuations also expanded, and the near uniformity was conceived." [12th critique]

JH-2: Reviewer's comment- "You gave a high importance of the development of the field and not necessarily the accomplishments themselves, it's almost like you are writing more the tradition of the science than of scientific accomplishments."

JH-3: Conclusion- "The truth that we are looking for all over the universe may be a difficult thing to find since our understanding of it is constantly shifting. This paper attempts to describe the conditions under which the scientific method has developed. Its flaws are recognized as being part of the system that allows them to unfold. The idea is that these flaws are not only recognized but also very much in the mind of those who call themselves scientists. Truth then is something circumstantial that may well change, and probably will, but sciences is not in the business of finding ultimate truths. The aims are

to find reliable evidence and with this evidence create concepts and theories that have a basis on which to stand on, not just wild conjectures of abstract ideas. This process is a part of history of the scientific method and will continue to be part of it until the discipline can no longer accept change. For the day that an absolute truth is claimed is the day as a science discipline will die, progress and development are essential to its existence. The end goal is infinitely moving away from us, but this is not built on some empty ambition. Instead it is a building block for improvement, an important that will and has led us question other realities as well as our own."

JL-1: Another Statement-"I feel like my overview should on concepts that I enjoyed and understood best..." [2nd entry]

JL-2: Next Paragraph- "This theory would almost perfectly explain why the current value of Ω is only 0.05 instead of 1...it would also explain why the universe is expanding at an accelerating speed. Because of gravity, big objects such as galaxies should be attracting each other and pulling each other inwards, but ... the opposite is true and galaxies are moving away from each other. With the existence of dark energy, which overcomes the gravitational tug of large masses, it would explain the perplexing expansion issue." [Final essay]

JL-3: Another Example- "Things on scales as small as atoms and electrons are the study of a specialized field of physics called quantum mechanics...the laws that govern the macroscopic world, or the world on the scale we live, do not necessarily apply at the atomic and subatomic scale. In the quantum world ...their position can only be determined by their probability of being in one place or another. This ambiguity in

quantum physics is aptly known as the uncertainty principle. The uncertainty principle states that the more you know about the specific aspect of certain particles, such as their location, the less you can know about the features such as momentum."

("Science is a field that strives that for certainty and yet Quantum Mechanics continues to efforts to nail down absolutes. Due to the stable structure of the physical world, I have to believe that the quantum world is not as erratic as it remains in that position until an external force moves it." [6th critique])

JL-4: Another Reviewer's Comment- "I thought that was pretty neat and it really helped put it in perspective. ... After rereading this I think I would have liked taking your class. May be next semester." [5th entry]

JS-1: "Heisenberg's uncertainty principle appears to demonstrate that accepting probability is not opposed to being certain (or at least as certain as possible) about the given phenomenon. In an interesting paradox, this acceptance of probability instead of the old certainty led to a relive of the problem of the contradictions between Bohr's model and Maxwell's theory of electrodynamics."

JS-2: Reviewers Comments-"You didn't make this clear." (Galileo's theory of inertia)

"How are certainty and probability is paradox? Pls. Explain."

JS-3: Views of science-"I have found some more technical aspects of this course challenging, I have been very surprised at the many similarities which seem to exist

between scientific narrative and philosophical narratives. The idea of progress is very much alive in both these domains."

KC-1: In the weeks 4 & 5, he tried to explain his thought about the wave particle duality of light, but that was vague. At this point he mentioned "the fitting of the spectral curve was something we got into pretty heavily. Lord Rayleigh and Sir J James Jeans produced their theory and it turned out to be an ugly one but it was held for a while based only on their reputations as leading physicists of the time. It took a while eventually Plank's theory was accepted." He did not explain properly how Lord Rayleigh and Sir J James Jeans produced their theories, why ultimately Plank's theory was accepted. In the following week's critique he pointed out in a same manner "that the electrons orbit around a proton neutron combination couldn't be sustained as that would cause the atom to collapse almost immediately was what Maxwell thought. Bohr tried to consolidate Maxwell's theories with Rutherford's findings." Further he noticed "quantum mechanics kind of phased that whole line of thinking out because it was found that electrons are waves and particles simultaneously. Schrödinger introduced the notion of probability that governs how you can observe the electron to be either one depending on how the experiment." [Critique Writing]

He explained his concept as Newton first thought that light behaves like a particle and at that time "Huygens came up with the theory that light was composed of waves. In order for Huygens wave theory to be verified it would have to account for something called diffraction that is the bending of light around an obstacle. It was thought that if light could be diffracted around an object such as a penny there would be a bright spot in the center directly opposite the light source. Later when Fizeau and Faucault showed that

light travelled slower when moving through a substance such as water than it did in empty space. This was clearly showed that light was a wave not a particle". He also said that Albert Einstein's photoelectric effect showed that light as a particle and in 1924 de Broglie submitted his Ph.D. thesis "based upon the theory that particles like the electron could have particle and wave like properties. Two years later electron diffraction was accomplished by Davission, Germer and Thomson. Soon after that Heisenberg and Erwin Schrödinger independently developed theories of quantum mechanics. They used these theories to describe the recent findings that uncertainty as well as probability both has effects on whether one can observe certain particles behaving as waves or particles and those photons and electrons can actually exhibit both at the same time." [Final essay]

LL-1: "It is embarrassing to say, Einstein and Copenhagen should shake their hand for they are repeating the old world view they have defeated. Wave and particle, observation and hypothesis, what is important depend on what scientist want to see. We are not able to mimic the way of photons but we can repeat the mind set of quantum physics which try to make configuration of all possible fact from everywhere....." [5th critique]

LGG-1: "These stars (Cepheid Stars) have a change in their luminosity from dim to bright (they blink). This blinking was called the Cepheid variable period-luminosity, which permitted other astronomers to evaluate the distances between these stars and us according to time it took them to go from dim to bright. This discovery was important because now we could have an idea of how far these stars were in our galaxy, but later on we found out some Cepheid's were further. Their light exceeded the distance of our galaxy, which would mean that they came from other galaxies. We know that one of the closest galaxies we have is the Andromeda spiral galaxy, which is 22 00 000light-years

from Earth, and that is why we could observe stars from that galaxy (Also it is pretty big)." [8th critique]

"The analogy we used to explain this occurrence is like water. Water when it in the most common form (liquid) and we put it in the freezer, it gets into another state (solid) and if we boil it, it becomes vapour (gas). Particles at the beginning they were in their initial state and then, with the temperature of the universe getting hotter, they have changed their composition, and when they cooled down, again they have changed in other particles (well, they are still the same particles but they appear different, like water and ice)." [9th Critique]

LGG-2: More important questions-"Why and how we got to know that these radiations (radiations emit from particles) existed? What kind of experiments did we do to understand these 'invisible waves'? And how does this apply to the wave-particle duality?" [5th critique]

MF-1: "The nucleus of an atom did have a heavy center containing electrically neutral neutrons and positively protons with light negatively charged electrons surrounding it. Most atoms are stable, meaning that they contain equal number of electron and protons, making them electrically neutral." [6thweek]

"It is a hypothetical form of energy (dark energy) that permeates all of space. By studying motion of stars and solar system of neighbouring galaxies, he (astronomer Jan Oorf) realized that galaxies were not decrepitly flying apart as they should have due to the ratio of kinetic energy vs. gravitation. There had to be a gravitational pull to keep stars from escaping galaxies, but there wasn't enough visible matter to account for this.

He was able to reason that there must be three times as much as is readily observed." [10th week]

MF-2: Introductory part-"Since its origins from the philosophical study of nature in ancient Greece, western science has deemed as the ultimate rationalistic system for building up knowledge. Over time, the discipline has been fine-tuned to experimental study in order predict the working of the physical world. However, to truly understand the nature of science, we need focus our attention to its course of development, societal functions as well as the processes of thought it produces.

As the discipline flourished and our schema of understanding evolved, so too did our perceptions become more complex and concrete. Science and academia intertwined to form an institution of hierarchies, bureaucratic standards and various codes of conduct. It served as the guiding light away from the heavy hand of church rule. This may be the point at which science became seen as something independent of faith, deriver purely from reason. Although this has helped the human race to advance technologies and dissect physical laws, the very foundation of science still proclaims certain convictions about our existence. Here lies the great contradiction, where scientific materialism regards itself as the only right view of reality, opposing that of monotheism and any religious doctrines. By going through an historical overview of the progression of physics, I will affirm that science is in itself a belief system; a manufactured framework which we look through to color our perception of reality."

MF-3: Conclusion-"The birth of the scientific method successfully reformed and compartmentalized the inert and physical aspects of the Universe. Science perfects skill

of breaking matter down into neat packages, but not in realizing the true nature of livings beings and the abstractions of consciousness. Institutionalization of this academic system also enacts limitations on individual thought and can stunt the growth of innovation. Objectivity fails to objectify itself. This exclusion of the observer limits conceptual thinking because it leaves you unaware of certain workings of the mind. Ignorance of oneself, beliefs and how they are looking simply leads to blindness. The evolution of knowledge and science serves as constant reminder that is so much more than we can imagine. Belief always comes before 'fact', literally altering how we perceive the world. It is this and not mere reason nor that will rational that will further continue to shape our reality."

MF-4: Reviewers Comments-"Try to have a better connection to all of your arguments by to developing more of a flow between paragraphs."

"Still need to further define certain terms and expand on some of the theories."

RW-1: Another concept-"Allowing for massive fluctuations in energy at the quantum level over very short period of time, Heisenberg's principle allows for momentary violations of the conservation of energy law. When sudden inflation of the universe occurred as a result of large scale symmetry breaking, these quantum energy fluctuations did not have the time to disappear again to their original energy level states and instead were magnified along with everything else in the expanding universe. The process of magnification through inflation essentially preserved this extra energy in space resulting in a large quantity of energy (and therefore matter) than the universe started out

with. In a sense symmetry breaking that led to inflation was more responsible for the creation of the universe we live in today than the initial bang."

RW-2: Another comment-"Need to look into Heisenberg's uncertainty principle. Seems to answer a complex question 'how can something come out of nothing'."

Explanation in the final essay: "The new notion of the nature of the particles can more accurately understood by probability than by our macroscopic experience was fundamentally inconsistent with classical deterministic thinking. And the only the only the indeterminacy at the quantum level was only reinforced by Heisenberg's uncertainty principle, a set of mathematical equations that relates to pairs of physical properties and that explains that the more accurately we try to measure on property in the pair, the less accurate our measurement will be of the other. This implies the position and momentum of a given particle, and the relationship between time and energy. ...Heisenberg's uncertainty principle is inherent in properties of all wave-like systems (and therefore all matter according to Schrödinger) and implies a fundamental limitation to our ability to understand particles."

TS-1: "The universe is bigger now than it was in the past and still expanding, however its expansion is slower ...this has raised the question of whether the universe will stop expanding and start shrinking. This theory has been labelled the big crunch. Scientists believe this will happen because of gravity; if you through a ball in the air, it will stop moving and come back to where it came from." [10^{th} critique]

TS-2: "I made a false statement saying the Milky Way is the center of the universe....There is no real center of the universe." [2^{nd} entry]

TS-3: Reviewer's comments-"Just because everything moves away from the Milky Way does not make it the centre of the universe." (He wrote "the Milky Way is at the center of the universe, it is where galaxies are created. Everything moves away from the Milky Way, the farther away it gets, the faster it moves. This means that we are always moving away and always gaining speed.") [8th critique]

TS-4: "Perception is also the question of what is really there as opposed to what we can actually see. If a non-scientist looked up into the night sky to look at the stars, they would normally think about how far away they are. If a scientist told they are actually looking hundred and seventy thousand years into the past, they would most likely not believe it at first. ... When a star explodes, it releases sub-atomic particles called neutrinos, which travel at the speed of light and pass through the earth. A supernova occurs at the interior of the star. Once it does, it crumbles and produces a blast of light. A supernova occurred in 1987, the blast of light could be seen in the sky and neutrinos were detected from the explosion. Like stars, most non-scientists would think the supernova happened on that day in 1987; however it had happened thousands of years ago. The light and neutrinos took thousands of years to reach earth travelling at the speed of light." [Final essay]

Appendix B

Table 9. How Helpful was the Course Dossier Method to Understand the Basic Concepts in Physics (Post Interview)

Students	How Helpful was Writing the Critiques	How Helpful were the Reviewers' Comments	Students' Personal Views about the Course Dossier Method after the Semester
JS	I need to explain more, and I think that was more helpful... I did explain things, but sometimes…there was very clear path from the critiques to the essay...		I think it was helpful to engage the material ... I found it's a very interesting process and did help me like better understand the things specially revisit some concept through all critique, it was helpful in that sense.
TS	It allowed us to make sure to understand the material that was presented in the class and way of basically formal lectures that were presented to us.	They were really helpful; because they were not taking the course...they are basically read in them or my perspective of the course, so found them very helpful.	When we write an essay thinking about what we writing but when you are giving exam you have to memorize facts, so personally I think it's better to write an essay. It may be changed my perception about what physics really is because priori taken this course I thought physics was basically testing the speed or velocity and motion of moving object but that's not really all of physics is. Physics is everything around us.

Appendix C

Interview questions:

Pre-interview questions: Before starting to ask you questions I would like to explain to you the meaning of pre-understanding/ pre-knowledge. Pre-understanding/ pre-knowledge means the knowledge you had learned/experienced before. For example maybe you have some ideas about space, galaxies etc. That means you have some previous knowledge about this course and these are your pre-understanding/pre-knowledge.

1. What is your pre-knowledge about physics/galaxies before starting the course PHYS-200?

2. What is your pre-understanding or pre-knowledge of this course in general?

3. How did you get this pre-understanding or pre-knowledge?

4. Do you think your pre- knowledge will be helpful to understand this course?

5. If Q. 4 is yes how and why?

6. What is your expectation from this course?

7. If you already know about the course dossier method from the course outline or from a class, do you think this method will fulfill your expectations?

8. If Q. 7 is yes how and why?

9. What is your personal thinking about the CDM before starting this course?

Post- interview questions: You used the course dossier method in your course PHYS 200; you know there were several activities like writing reflection (preview sheets), critique writings, final essay writing, I would like to ask you several questions on those activities. Let start…

1. How did you prepare your preview sheets (reading reflections) before the lectures presented in the class?

2. What did you do when you were preparing your preview sheets?

3. How did these writing reflections influence you?

4. How did you prepare your critique sheets (concept reflections) after the lectures presented in the class?

5. What did you do when you were preparing these sheets?

6. What do you think was the point of writing a preview sheet?

7. How did the preview sheets influence your critique writing?

8. How did the critique writings open up your views on science?

9. What do you think was the point of writing a critique?

10. How did you prepare your final essay?

11. How helpful were your friends' comments on your writing final essay?

12. What was the impact of your critique writings on your final essay?

13. Did working on the course dossier change your ideas about material in the course? (Probe: if yes, in what way?)

14. After the course what is your personal thinking about the course PHYS 200?

15. What are your personal feelings about the course dossier method?

16. Do you think the course dossier method helped you to fulfill your expectations in this course? (Probe: if yes how?)

17. Has this course changed your ways of thinking about other people's ideas? (Probe: if yes how?)

18. What do you think was the point of writing a course dossier?

19. Has this course changed your perception about science? (Probe: if yes how?)