Teaching Nature Of Science (NOS) With Student-Centred Instruction

Fereshte Heidari Khazaei

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THIS IS TO CERTIFY THAT THE THESIS PREPARED BY:

Fereshte Heidari Khazaei

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Dr. Laszlo Kalman **CHAIR**
Dr. Mariana Frank **EXAMINER**
Dr. Bruce M. Shore **EXAMINER**
Dr. Calvin S. Kalman **SUPERVISOR**

APPROVED BY Dr. Pablo Bianucci
Chair Of Department Or Graduate Program Director

André Roy **DEAN OF FACULTY**

DATE **August 16, 2018**

ABSTRACT

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Fereshte Heidari Khazaei

The Nature of Science (NOS) covers the aim, development, criticism and explanation of science (Abd-El-Khalick, 2001; Hickey, 2005; Lederman, 1992; Matthews, 1994; McComas, 2004). This study examines the impact that studying philosophy and history of science has on undergraduate students' views about the NOS. Studying philosophy and history of science can also enhance students' critical thinking skills. It helps students to understand what science is, how to characterize the nature of its practitioners' activities, and what is the significance of the whole enterprise.

Having students study scientific concepts through the eyes of philosophers and historical scientists actively engages them in the process of inquiry and challenges them to increase their understanding of the NOS.

This study showed that studying philosophy and history of science in a student-centered classroom had a strong influence on students' views about the NOS in that many students changed their views about the NOS. Students who did not change their over-all perception gave much clearer expositions of their views.

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Chapter 1: Theoretical Context

1.1 INTRODUCTION

I was always fascinated by philosophy and the history of science. When I was in high school, I was given a book named "Heisenberg Probably Slept Here" (*Brennan, Richard P., 1997*) that changed my entire outlook on science and how the scientific method is used to give a clearer picture of reality. The book covers philosophers and scientists in history and took me to a voyage into how great minds work. I strongly believe that it piqued my interest and from that point onwards I committed myself to learning physics. Apart from just studying physics, I delved deeper into the workings behind it as well which led me to take courses on the philosophy of science and philosophy of quantum mechanics and history of science. Attending these courses helped me to broaden my horizon in achieving a scientific mindset and opened new vistas on looking at science in general. While at the university, I observed that a considerable number of my peers dropped out of the discipline or the university altogether. I concluded that there was a problem in the way the courses were delivered to students and the methodology or teaching style was inherently flawed. The lack of interaction between the lecturers and students, the monotony of the lectures, shortage of related examples and improper class schedules made it difficult for students to concentrate and develop enthusiasm for the subject they were learning. There was an absence of belonging in the students who were studying science and I believe that introducing them to the nature of science (NOS) by considering historical material in relation to modern philosophers of science can help achieve relevance and Intercontextuality.

1.2 Purpose of the study

The purpose of this study is to investigate the effectiveness of teaching the Nature of Science (NOS) in a student-centered classroom, specifically SCOL 270, a 6-credit course on the historical, philosophical, and social aspects of science. For most students, this was their first course in which the NOS was addressed.

In SCOL 270 the intellectual framework of science and the relationships between science and society, and the political and philosophical questions inherent in the scientific process are presented. It is a course exploring the nature of science from a multidisciplinary perspective.

This study explored changes in students' understanding about the NOS. Through systematic analysis themes were generated and comparisons between pre- and post-course data demonstrate that students improved and deepened views about the NOS that are more aligned with NOS literature.

This study sought the answers to the following major research question:

Does studying the Nature of science in a student-centered classroom change students' conception of Science?

1.3 Statement of the Problems

Clough (2006) described the nature of science (NOS) as: "what science is, how it works, the epistemological and ontological foundations of science, how scientists operate as a social group and how society itself both influences and reacts to scientific endeavors" (p.463).

The nature of science (NOS) education plays an important role in disseminating science culture and it is an important way to examine scientific culture. Today there is a broad consensus on recognizing the curricular relevance of the nature of science (NOS) to improve students' scientific literacy. In particular, students' conception of science can be improved by including the NOS in the curriculum. (Acevedo 2008; Coll 2012; Lederman 2007).

However, teaching of the NOS is not always effective: simplistic or erroneous conceptions of science sometimes persist. Understanding issues associated with the NOS is considered a vital component of scientific literacy worldwide (e.g., American Association for the Advancement of Science [AAAS] 1990; Lederman et al. 2015; Millar and Osborne 1998; Osborne et al. 2003; Wahbeh and Abd-El-Khalick 2014).

Identifying effective means for teaching the NOS has become a central focus for science education in recent years. Studies have shown that, among children, adults, science teachers, and even scientists, an understanding of the NOS is meager at best. For example, 70% of the American adult respondents to the 2001 National Science Board Survey of Public Attitudes Toward and Understanding of Science and Technology did not hold an adequate ‘‘understanding of the scientific process’’ (National Science Board 2002).

1.4. Proposed Strategies to Address the Problems

Student-centered instructional methods may be important in teaching the NOS. There has been considerable interest over recent years in the effects of interaction in classrooms. Studies on the effect of employing active versus passive learning activities on learning outcomes [e.g., Chu and Libby, 2010; Hermanson, 1994] have found that active learning is positively associated with student performance. Claims are made that teachers talk too much in the classroom, and that it is essential to minimize teacher talk and increase learner talk. It is often suggested that teacher-talk does not reflect real language and so is inappropriate input, whereas if learners are negotiating more meaning, this will lead to more comprehensible input (Kennedy, 1996). Active involvement/participation in the learning process is essential to success in university. Student engagement is important in terms of educational outcomes such as achievement, persistence and retention (Kuh, et. al., 2008). Empirical studies have confirmed that students report high perceived needs satisfaction when taught in a student-centered way. (Minnaert, Boekaerts, and de Brabander, 2007; Müller and Louw, 2004; Smit et al., 2014). In order to foster critical thinking and to equip students with essential cognitive and communicative skills, a combination of student-centered instruction methods was used in SCOL270, including "reacting to the past" role-play, inquirybased debates, *reflective writing* and the *course dossier method*.

1.4.1. "Reacting to the past" role-play: Living history and learning through re-enactment

The simulation of history has interesting consequences resulting in participatory inquiry. The concept of *reacting to the* past (RTTP) was first implemented by Mark C Carnes at Columbia University(Carnes,2004), as a technique where students go through an immersive experience about the life and times of scientists of a specific era by roleplaying characters. This pedagogical technique actively engages students to understand and analyse situations while critical thinking becomes automatically a part of the entire process. Jacob Moreno, a psychologist from the 1900s, aptly uses the term "psychodrama" to best describe this interactive approach(Moreno,1995).

In RTTP, class sessions are run entirely by students who play it like a game scene and instructors advise and guide students and grade their oral and written work. Before the theatrics, students must extensively go through the texts to understand scenes and scenarios. Students are encouraged to write essays on what they understood of the content, which establishes a solid background on sense making of what they are about to do.

Examples, which were carried out at SCOL 270, were the Trial of Galileo and the Darwin game. In the trial of Galileo students enacted the whole scene in which Galileo had to face the consequences for introducing new ideas differing from the accepted views. In the Darwin game, students were assigned in groups of conservatives and more liberal characters. They discussed Darwin's grand idea of evolution by natural selection and whether the Copley medal (a scientific award given by the royal society for outstanding achievements in science) should be given to him or not. Students had to engage in a debate which encourages their fact building skills using logical arguments.

1.4.2. Reflective Writing

Reflective writing is a student-centered approach widely used in science and engineering courses that helps students develop a holistic scientific mindset. (Huang and Kalman, 2012) Students come into science classes with their own perceptions and beliefs. They have great difficulty reading scientific texts. The language and epistemology of science are like a foreign culture. Based on the hermeneutical perspective in science education, there exist two horizons (Gadamer 1975, p. 272). One that contains everything that students believe and the other horizon encompasses all the textual material. 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 and Robinson, 2011).

Step 1: When students read the text, they build their new horizon. This horizon is the combination of student's parts i.e. the student's pre-understanding, experience from their life world and experience from the textbook. This is the student's whole. The text whole is a combination of its parts (Khanam and Sobhanzadeh, 2014).

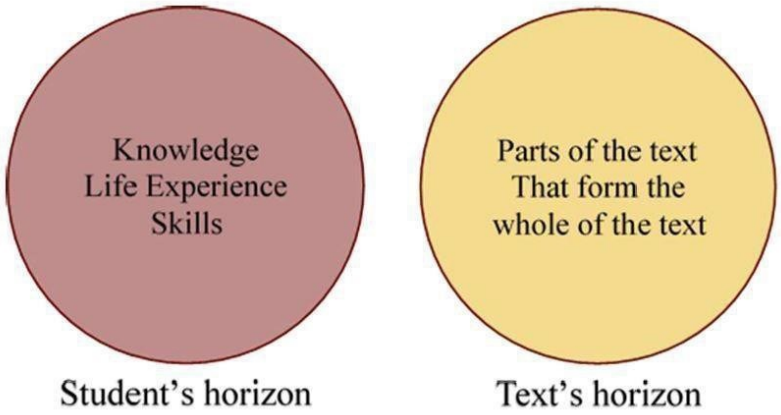


Fig.1.Horizon 'A' of Students and 'B' of Author's Horizon of the Textbook

Step 2: When students are looking at a 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 part of the textbook. In reviewing the part again, they may discover, more contradictions. In this case, their horizon shifts in the direction of the horizon projected by the textbook. 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. (Figure 2)

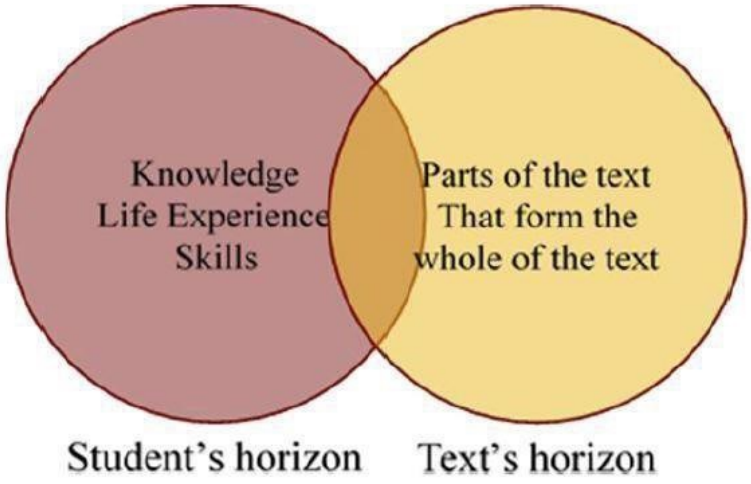


Fig.2.Students' horizon shifted to the horizon projected by the text

Reflective writing helps the student horizon to come closer to horizon of the textbook. (Kalman, 2011)

After reading a text, students are asked to look back at the text and try to analyze the concepts and reflect on them from different perspectives. The practice of Reflective Writing is carried out by students while reading material to improve understanding and facilitate future

class discussion. Before covering the material in class, the teacher would ask the students to read the material in their textbooks, as homework, then to write and reflect about what they have read. (Connally, 1989).

1.4.3. Critique

After a class discussion, students were asked to write a one-page post-summary of the discussions occurring in 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. In writing the essay the students pick one or two of the most important concepts from the lectures presented in the class in that week and then critically analyze those concepts in 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 marks are deducted for unnecessary use of mathematics and extra pages are not read (Kalman, 2018).

In SCOL270, a one-page critique is written that consists of the concepts that were covered in the class discussion between students including the professor's short lectures that were given at the end of the class.

1.4.4. Inquiry-based debates:

Much empirical research on classroom practices shows the importance of *teachers framing connections* between everyday knowledge and scientific knowledge, rather than treating content as entirely new and disconnected from other learning contexts. (Bransford and Schwartz, 1999; Cornelius-White, 2007; Littleton and Mercer, 2013; Erstad and Sefton-Green, 2012)

Group discussion is useful to frame these connections and encourage students to evaluate material critically. Having performed Reflective Writing in SCOL270, students are familiar with the subject matter. The teacher would divide students into 4 groups. Two groups would debate two different points of view related to the subject matter and a third group would design questions to ask them. The fourth group oversees evaluating the pros and cons of each argument and decide the winner of the debate.

1.4.5. Course Dossier Method

The Course Dossier method (Khanam, and Kalman, ,2017) is a writing-to-learn tool. 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 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 and Putney, 2002). Moreover, Vygotsky believed that learning and development of thinking are an interrelated, dynamic process (Wink and Putney, 2002), because 'learning is not development' but properly organized learning causes mental development.

The idea of the course dossier method is also to use writing procedures based upon Gadamer's hermeneutical approach (Kalman, 2008). As it was explained in section 2.2, The hermeneutical circle is the fusion of the learner horizon and horizon of the text.

In this method students used different kinds of writing activities (during the course): writing reflections (before students came to class), 'Critiques' (after class) and final essay writing (Course Dossier with six entries) at the end of the course. Students are asked to review the critique essays and have their essays to be reviewed and reflected upon by people who did not attend the course. Using their reflections, they write a single overview of the course content.

1.5. Literature review

The importance of accurately and deliberately teaching the NOS when teaching science to students is widely recognized (Clough and Olson 2008). A main goal of science education is to create scientific literacy and a scientific literate person needs a deep understanding about the NOS (Akcay, 2015). Akcay also states that understanding the NOS is a critical objective and to achieve this understanding, students need to learn about the processes through which science develops. Abd-El-Khalick and Lederman (2000) distinguish between implicit and explicit approaches to NOS instruction: Implicit NOS instruction assumes that students can learn the NOS target, not a side effect of the learning experience. Aspects of the NOS are directly addressed with students by ''doing science.'' Students engage in science-based activities, but NOS issues are not specifically addressed. In contrast, explicit NOS instruction takes NOS learning to be a direct target, not a side effect of the learning experience. Aspects of the NOS are directly addressed with students. The focus of this study is explicit NOS instruction and (SCOL 270) is a course exploring the nature of science as a direct target.

The development of adequate student conceptions of the nature of science has been a perennial objective of science instruction regardless of the currently advocated pedagogical or curricular emphasis (Lederman, 1992).

Support for Lederman's idea is found in an experiment in a calculus-based introductory physics course on optics and modern physics reported in Kalman (2002, 2010). Students study one philosopher all semester as a group project and report regularly on how their philosopher would view the subject matter of the course. Students were asked about their views at the beginning and end of the course, Students had essay questions about the NOS on the midterm and final examinations. Students submitted five essays about the philosopher of science, whom they were following during the course. There is thus not only a great deal of information about each student to analyze, but also enough information to triangulate the information. It was found that the course had a strong influence on students' views of the NOS in that many students changed their views about how theories evolve. The students seem to have made a marked improvement in their critical thinking skills and in their grasp of the underlying concepts of the subject matter of the courses.

Some NOS researchers have sought to determine if some contexts are better suited to learning the NOS than others (Bell et al. 2011; Khishfe and Lederman 2006, 2007). Their results indicate how varied contexts support student learning of NOS as long as the explicit and reflective framework also informs NOS instruction. For instance, Kruse (2017) explored changes in preservice teachers' (PST) nature of science pedagogical (NOSP) views and NOS rationales using pre- and post-course written responses as well as interview data. As a result, he suggested that students' conception of science can be improved by including NOS in the curriculum.

A study that investigated teaching experiences applying History and Philosophy of Science (HPS) in a physics classroom, with the aim of obtaining critical and reliable information on this subject was done by Carvalho and Vannucchi (2000) in Germany.

This study involves qualitative research with a group of secondary school students on the historical development of Optics, especially events involving Galileo using a telescope. Group

activities took place in a classroom with questions proposed and mediated by the teacher. After reading and analyzing historical texts there were activities in which students discussed the subject with a view to better understanding essential aspects of science, as well as learning how to develop arguments and appreciate attitudes as to the direction of science. The authors presuppose History and Philosophy of science (HPS) to be an "integral part of scientific knowledge, and therefore, they must be studied in science courses" (Carvalho and Vannucchi 2000, p. 427).

Another study was done by Klopfer and Cooley (1963) in the USA. The researchers evaluated the effectiveness of the HOSC (History of Science Cases) instructional method in students‟ understanding of the NOS and the subject of physics. The study involved diverse groups of secondary school physics, chemistry and biology students, although the present research summary restricted the scope of the analysis to physics groups. During the four weeks in which the investigation was carried out the physics groups looked at Optics (Fraunhofer lines and speed of light) and Hydrostatics (atmospheric pressure). The teaching strategy involved reading and discussing history of science cases, utilizing historic texts along with original articles, experiments and exercises relating to the cases.

Research was also done by Galili and Hazan (2000) in Israel. The Influence of an Historically Oriented Course on Students' Content investigated the effects of a one-year Optics course that incorporated historical materials about light and vision models on students‟ perceptions about the NOS and technology and the extent of subject knowledge. HPS was introduced through historical texts in terms of drawing parallels between the students' conceptions and historical conceptions of the concepts of light and vision, although no specific teaching strategy was suggested to the teachers who ran the course.

All the studies presented entirely favourable results. This shows that in the teaching of physics the use of HPS-based approaches may in fact foster a more mature student vision in respect of their understanding of the NOS. Thus, physics curricula and/or teaching that include in their objectives provision for the students' better understanding of NOS, may find an effective ally in HPS.

1.6. Theoretical framework

What is science and scientific knowledge? Are scientific laws and theories discovered from nature? Or, are they invented by scientists and their community?

The discipline of Nature of Science (NOS) seeks to answer these questions. It deals with the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman, 1992). Lederman (2007) also discussed seven aspects of NOS which need consideration in science education. These characteristics of NOS are listed as tentative, empirically-based, subjective, socially embedded, the distinction between scientific experiments and interpretation. The relationship between scientific theories and laws and the process of evolving a theory were considered as different aspects of scientific knowledge.

Here, I provide parts of discussions and philosophers views on the NOS and the process inherent to the development of scientific knowledge which were emphasized in SCOL 270. All the following material was taught to students using student-centered teaching:

1.6.1. Popper's Philosophy of science

The first modern philosopher of science who was discussed in SCOL 270 was Popper. Students wrote Reflective Writings and critique essays about Popperian points of view and they engaged in group discussions about his philosophy of science. Karl Popper's philosophy of science uses modus tokens as the central method of disconfirming, or falsifying, scientific hypotheses. Scientists start with a current scientific theory and use the usual methods of deductive reasoning to derive specific conclusions, of which some are "predictions" (Ralph E. Kenyon, 1984). Strictly deductive reasoning is "truth preserving", that is, it is such that if one starts out with "true" premises, one can only deduce "true" conclusions. Starting with a "theory" and deducing "predictions" can be stated in the form of a premise:

If the theory is true, then the prediction is true.

Popper shows that we cannot prove that a theory is true, but we can certainly show that a prediction is false. If the scientist tests one of these predictions and finds out that it is not true, he uses modus tollens to conclude that the theory cannot be true:

If the theory is true, the prediction is true.

The prediction is not true.

Therefore, the theory is not true.

In Popper's view a scientific theory should be:

Falsifiable, Testable and refutable.

1.6.2. Bacon ‘s philosophy of science

Francis Bacon was also discussed in SCOL 270. Bacon has a more empirical point of view about scientific knowledge. To test potential truths, or hypotheses, Bacon devised a method whereby scientists set up experiments to manipulate nature and attempt to prove their hypotheses wrong (Ashgate Publishing, 2013). For example, to test the idea that sickness came from external causes, Bacon argued that scientists should expose healthy people to outside influences such as cold, wetness, or other sick people to discover if any of these external variables influenced the control group. Knowing that there might be multiple factors leading to sickness which would not be detected or would be ignored, Bacon insisted that these experiments must be consistently repeated before truth could be known: a scientist must show that patients exposed to a specific variable frequently got sick over and over. He believes in probing nature with nature as he argues:

“All depends on keeping the eye steadily fixed on the fa cts of nature.”

Bacon encourages scientists to travel over the earth collecting facts, until the accumulated facts reveal how Nature itself works.

1.6.3. Thomas Kuhn: Dynamics of the nature of science and educational reforms

Thomas Kuhn’s idea that scientific revolutions come in phases changed the way the world thinks about scientific progress and the nature of science. The conclusion that Kuhn drew was that the nature of scientific process was non-cumulative and rather circular going through phases of normal science, crisis, and revolution. The central tenet of his book, The Structure of Scientific Revolutions, introduces the idea of paradigm — an intellectual disciplinary framework which makes research possible. Researchers engage themselves within this paradigm through a puzzlesolving attitude (dubbed “normal science”) to bridge the discrepancies between

predictions and observations. Over time, anomalies may accumulate leading to a crisis and a paradigm shift. This is a very different approach as opposed to the views of realists like Popper, to whom science is primarily concerned with problem-solving, innovation and exploration.

A tempting question to ask now is whether educational reforms in science can be understood as paradigm shifts through a Kuhnian lens. According to Kuhn, normal science education is a form of indoctrination as students are initiated into the dominant paradigm of the day by their educators and the methods and content of the paradigm are accepted without questioning (Kuhn 1963, p.357). The only way to graduate to another paradigm is to forsake the traditional methodologies as normal science is marked by a lack of debate on the basic concepts (1970, p.6). Continuing with Kuhn's analogy, such a paradigm shift would trigger a resistance on the practitioners' side. It can be argued that the major reason for the resistance to change on the teachers' side could be the difficulty (if it is not impossibility) for teachers to comprehend the conceptual framework of the reform (or the new paradigm) as this requires denying the previous educational context in which they established themselves. Fullan (1991) argues that the core values developed by individuals over time regarding various aspects of education are difficult to change as such values are "often not explicit, discussed, or understood, but rather are buried at the level of unstated assumptions" (p. 42). As is the case, that the greatest resistance would come from the more experienced teachers, whereas the new teachers may be more open-minded.

1.6.4. Components of nature of science

A) Tentativeness

Science and scientific knowledge are tentative. That does not mean that scientific knowledge is wrong, but it does mean that it can be modified or replaced when new interpretations of existing data and new evidence become available. At the same time, scientific knowledge is also durable since it rests upon the ongoing support of evidence (NRC, 1996).

Uncertainty and tentativeness are characteristics for empirical results (Popper, 1968; Bromme and Goldman, 2014). “Instead of solid knowledge, we should get used to the notion of tentative information” (Ioannidis, 2006). Understanding tentativeness also means to comprehend that these findings may contradict each other or become obsolete when more reliable findings occur (Sinatra et al., 2014).

B) Subjectivity

Subjectivity has become a central topic in the formation of scientific knowledge (Hansen, 1958, cited in Hickey, 2005; Kuhn, 1962). It recognizes that observations are not completely objective, but are affected by related scientific theories. In addition, when scientists analyze and interpret the data that they have gathered, results can be biased and limited by scientists’ prior knowledge (Bell et al., 2003; Lederman et al., 2002).

Scientists do not conduct absolutely objective observations, do not reach objective conclusions and do not evaluate new evidence objectively (Lederman and Abd-El-khalick, 2002)

Just as students’ interpretations of observed phenomena are influenced by their beliefs, values and previous knowledge, so too are those of scientists (Lederman, 2007).

C) Social and Cultural Influences on Science

This concept examines whether students view the scientific enterprise as non-cultural and nonhistorical, or as multicultural and history-embedded. Historians in the philosophy of science such as Hickey (2005) have agreed on distinguishing the context of discovery from the context of judgment, and some science educators acknowledge this view (Chalmers, 1999; GodfreySmith, 2003; Matthews, 1994).

Many factors, such as historical and social factors affect the scientific process. In the context of this concept we examine whether students view the scientific enterprise as noncultural and nonhistorical, or as multicultural and history-embedded. Different aspects of the NOS are shown in Fig.3.

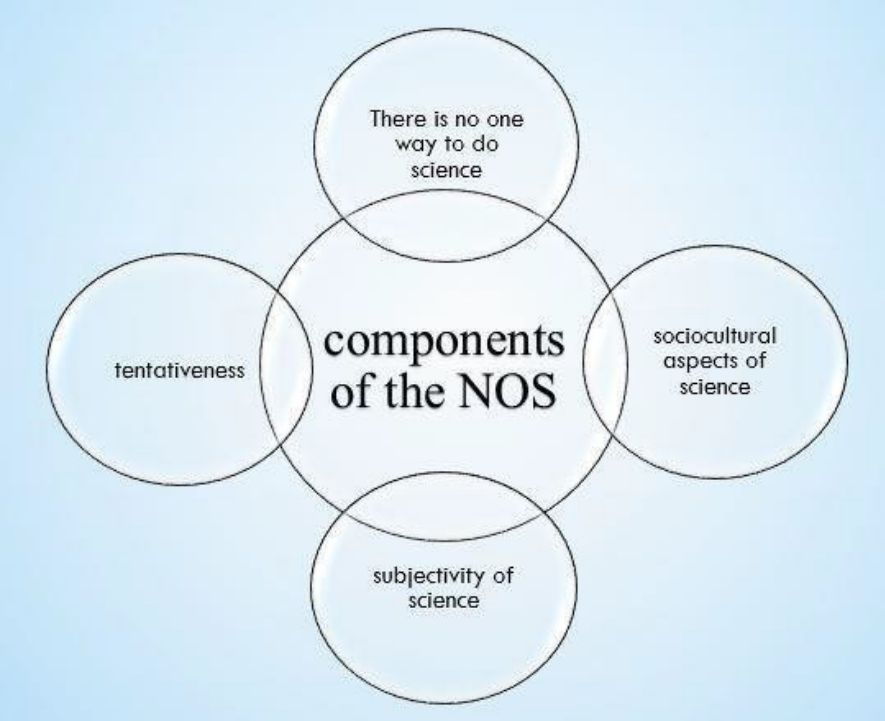


Fig 1.3. Components of the NOS

Chapter 2: Methodology

2.1 Introduction

This chapter outlines the methodology for this research. Qualitative methods (Creswell, Plano, Clark, 2007; Greene, Caracelli, Graham, 1989) were employed using semi-structured interviews, observational data and qualitative research on students' writing products. The data were collected from first and second year university students taking SCOL 270 and analyzed with the methods, which this chapter explains.

This chapter is organized into three sections: 1) the first section introduces and outlines the research design; 2) the second section explains the method of collecting data focusing on the instrument for this study; 3) the third section explains the examination of the instrument validity and reliability.

2.2 Qualitative inquiry approach

Multiple case studies were used in this research. Case studies have been largely used in the social sciences and have been found to be especially valuable in practice-oriented fields (such as education). "Much of what we know today about the empirical world has been produced by case study research, and many of the most treasured classics in each discipline are case studies" (Flyvbjerg, 2011). Case-study research builds an in-depth, contextual understanding of the case, relying on multiple data sources (Yin, 2018). Case-study research is presented as an inquiry strategy, a methodology, or a comprehensive research strategy (Denzin and Lincoln, 2005; Merriam, 1998;).

Mesec (1998) gave a broad definition of case study:

It is a description and analysis of an individual matter or case […] with the purpose of identifying variables, structures, forms and orders of interaction between the

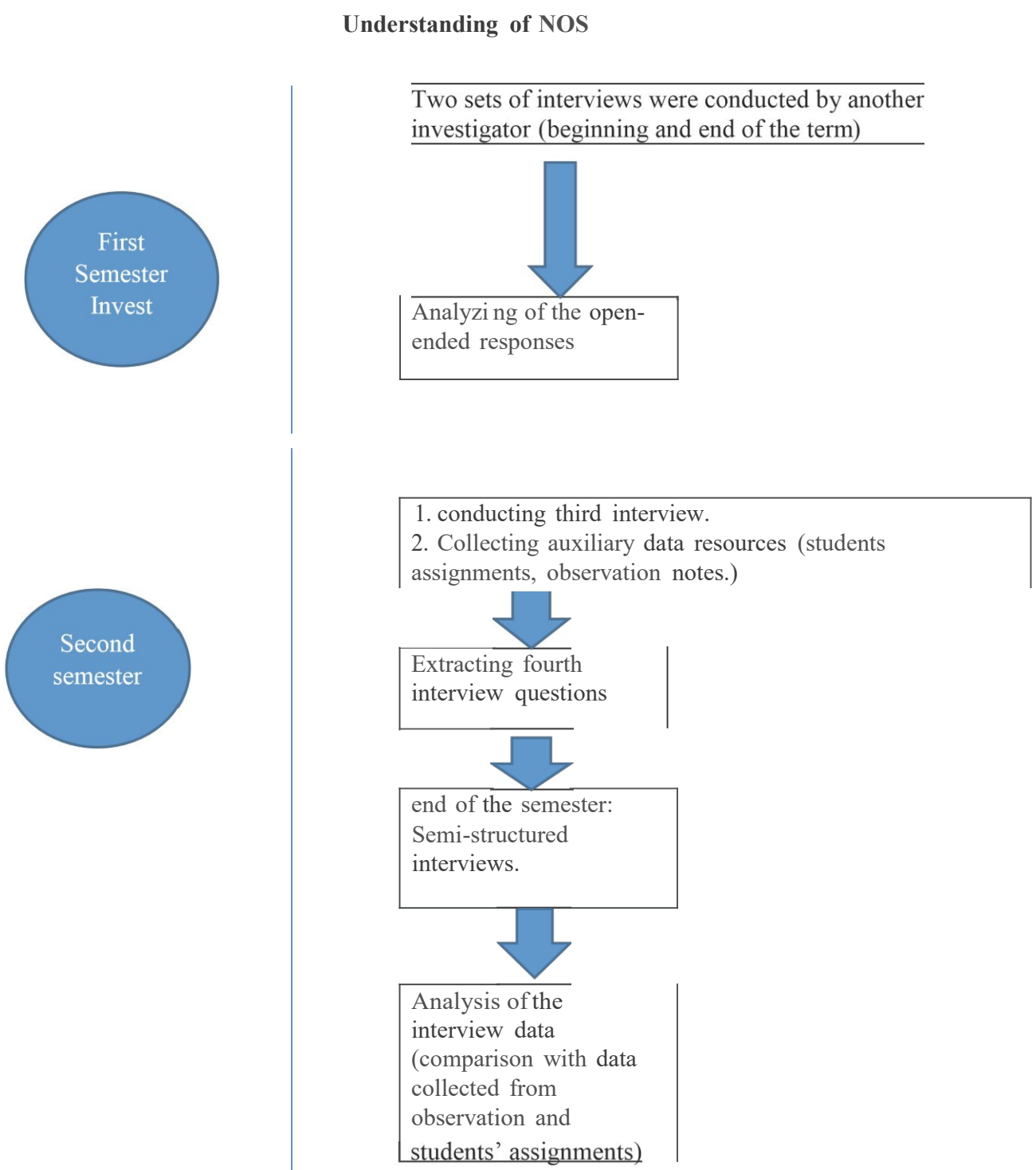
participants in the situation (theoretical purpose), or, to assess the performance of work or progress in development (practical purpose).
(p. 383).

In a collective or multiple-case study, the researcher again selects one issue or also selects multiple case studies to illustrate the issue and to show different perspectives on the issue (Creswell, Hanson, Clark Plano, Morales, 2007).

In general, case studies are the preferred strategy, when the investigator has little control over events, and when the focus is on contemporary phenomenon within some real-life context (Yin, 2018). Considering the discussed aspects of case study research, it seemed best to adopt a case study approach.

Interviews are the most important method of data collection in case studies. Semistructured interviews allow researchers a more comprehensive understanding of students' views, reasons and resources informing the beliefs that students have and the way in which students' views affect their learning (Aikenhead, 1987; Lincoln and Guba, 1985). Semistructured interviews brought an in-depth understanding of participants' points of views on the NOS. Despite these benefits, interview or open-ended questions cannot include many participants. Categorizing, sorting and coding data consume time (Sudman, Bradburn, 1983).

This project was conducted in a two-semester course. (Figure 2.1). Figure 2-2 presents research question and related data sources as well as analytical methods.



Fi e2-1. Research design and process

Table 2.1. Research questions, Data and Analysis

Research Question	Data	Analysis
Does studying Nature of science in a student-centered classroom change students' conception of Science? Purpose: To identify effectiveness of teaching NOS in a student-centered class	Students' interviews Observation notes Students' assignments	a. Coding (identifying major themes and categories based on literature review and concepts discussed in class b. Listing c. comparing themes and making conclusions

2.3 Participants

The chosen group of participants taken as a convenience sample were idealized candidates and thus served as representatives for all students enrolled. A range of methods was employed to analyse different parts of the project.

In this multiple case study (Yin, 2018; Stake, 1998; Merriam, 1988), the participants were selected from students enrolled in science college course SCOL 270 (titled Historical, Philosophical and Social aspects of science).

There were two levels of in the study:

The first level of participation – for all students. Participants were asked to agree to being observed in the classroom by the investigator. They were asked to agree to have their essays, reflective writings and course dossier assignments analyzed by the investigator after they have been graded by the instructor.

Second level of participation –for students who agreed to be interviewed. In addition, students who have agreed to take part in interviews were interviewed for approximately forty minutes at the beginning middle and at the end of the course by the investigator. Interviews took place at Concordia university, outside the classroom.

The purpose of this study was to investigate the effectiveness of teaching the Nature Of Science (NOS) in a student-centered classroom.

There were three types of data collected for every participant:

(a) their answers to questions in a semi structured interviews (Merriam, 1998) and (b) The writing products of the participants, (C) data collected from in class observation.

To best generalize the results, as suggested by Yin (2018), representative students were selected as interview participants. Interview participants in this study were 6 science students in their first year at university. All the participants were taking SCOL 270.

2.3.1 First year participants

The science college course titled Historical, Philosophical and Social aspects of science at Concordia University (SCOL 270) was examined in 2015-16 in Fall 2015 by one researcher. The class consisted of 20 science undergraduate students mostly in their first year enrolled in honours programs in biology, chemistry, physics, mathematics, psychology and the department of health, kinesiology, and applied physiology. A researcher participated in all of the classes and interviewed six students enrolled in the course at the beginning and end of the first semester. He interviewed four females and two males. His thesis was on student-centred learning (SCL) and showed students derive significant benefits from having positive interactions in class.

2.3.2 Second year participant

I examined the course in 2016-17. I participated in the same course in both of the semesters and interviewed six of the 19 students from the same departments as in 2015-16 enrolled in the course at the beginning and end of the second semester. To blend the data from both researchers the same questions from the end of the first semester in the 2015 -16 course were used in the beginning of the second semester of the 2016-17 course. There were 4 females and 2 males. Both courses were taught by the same instructor, who was not part of the research team and who taught the course in the identical manner both years. The withdrawing policy was stipulated in the consent forms. Use was also made of all the students' assignments throughout the second semester. The first condition for selecting interviewees was students' willingness to join the interview; the second condition was diversity in their fields of studies.

2.4. Validity and reliability of the research

To promote the credibility of the study, I emphasize that prolonged engagement occurred in the sense that I observed the class in 26 weeks (throughout fall and winter semesters). Triangulation was used to establish credibility. Triangulation refers to the use of multiple methods or data sources in qualitative research to develop a comprehensive understanding of phenomena (Patton, 1999). Triangulation also has been viewed as a qualitative research strategy to test validity through the convergence of information from different sources. Denzin (1978) and Patton (1999) identified four types of triangulation: (a) method triangulation, (b) investigator triangulation, (c) theory triangulation, and (d) data source triangulation. The current study benefited from data source triangulation.

Three sources of data were used: Reflective Writing assignments, interviews, and class observation. Moreover, the results of the analysis of Reflective Writing products were compared to the results of the interview analysis to assess whether they corresponded or conflicted with each other.

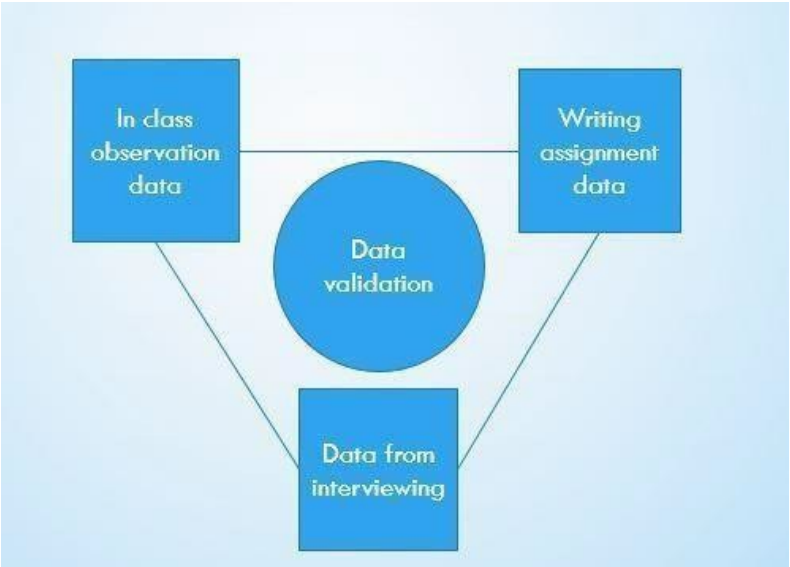


Figure 2.2. triangulation method

2.5. Ethical Considerations

In terms of confidentiality. Potential participants were invited to participate in the study by means of a recruitment letter printed on Concordia letterhead distributed in the class(appendix A). The letter briefly described the nature of the study as well as both levels of participation. Interested students were asked to sign and give the letters back. In this way the research team will know the participants' real identity, but it will not be disclosed**.**

Students who choose not to participate did not have their assignments analyzed and no information from them was recorded during observation periods. Participants were informed that they have a maximum of one month after the initial signing of the consent form to contact the researcher with a request to withdraw their participation. This was one of the items on the consent form. If a participant requests to withdraw from the study, analysis of his or her assignments would be excluded from the analysis and, if an interview was carried out with him or her, the audiorecording will be deleted and the paper transcript of the audio recording will be shredded. There was the potential benefit for students to reflect more deeply on their learning experience and thus enhance their learning outcomes from the course. The data should contribute to increasing understanding of the factors that enhance learning, student engagement, and conceptual change. Due to the nature of the study and interview questions, the present study did not have any foreseeable risks for the physical or psychological wellbeing of the participants. However, it is acknowledged that it is always possible that participants may experience some distress when interviewed about the challenges of the course. If this situation should occur, I would offer the participant to end the interview and would provide the participant with the phone number of the Applied Psychology Center (APC) and counseling and development services at Concordia. To minimize the risk of distress, using the oral consent script l informed the participant that the interview can be ended at any time if he or she does not feel comfortable. The research team (Dr. Kalman and I) knew the participants' real identity, but it would not be publicly disclosed. Assignment copies, observation notes, interview transcripts and audio recordings were digitalized and stored on a password protected computers owned by Dr. Kalman and me from Concordia University. Only Dr. Kalman and I had access to the data collected. The instructor (Dr. Leblanc)

was blind to which students were participating and did not have access to any of the analyses. All data will be kept for a period of five years and remain in possession of Dr. Kalman and myself. The data from this study was analyzed and may be published in academic journals or conferences without disclosing the participant's identity.

3. RESULTS OF THE QUALITATIVE DATA ANALYSIS

3.1 Introduction and Overview

This chapter reports the analysis of responses to the semi-structured interview questions about the NOS. This qualitative data provides in-depth understanding of the students' conception of the NOS. Section 3.2 describes the features of responses to the semi-structured questions about the NOS for the first semester of SCOL 270, with subsections for each NOS concept: Tentativeness, Subjectivity, Sociocultural Embeddedness and Diversity of Scientific Research Methods. Section 3.3 sets out the semi-structured interviews and other data collected for the second semester of SCOL 270. Common themes are grouped together, and the students' opinion about their evolving understanding of the nature of a scientific theory is reported. The crucial point of the interviews was to identify the impact of student-centered teaching on students' understanding of the nature of science. The last section, 3.4 includes a summary of the qualitative data analysis and reiterates the main findings relating to the research question.

3.2 Responses to the interview Questions (First semester)

The semi-structured interview questions for this study were designed to evaluate students' conception of science. Interviews allowed us to compare students' attitudes towards the NOS at the beginning of the fall semester with how they define their view of science in the postinterview. They explained their views of science and talked about the changes in their ideas during the semester. In the post-interview, all interviewees except for student N mentioned that they no longer thought that science was straightforward. All interviewees experienced changes in their understandings about science during the semester. They all believed that the Galileo Game had a positive role in understanding how science works. Table 2 shows the interviewees' explanations of science during the pre- and post- interviews.

As can be seen in table 2, in the pre-interview, students O, K, and L mentioned that science progresses through observation and experimentation. During the post-interview they all mentioned many factors, such as historical and social factors that affect the science process.

In the pre-interview student P explained that scientists go from the questions they have in their mind and the things they know which they use to develop a hypothesis. In the post-interview there is a change in his attitude as he explained:

"Science is a much more complicated process than I thought! Because it's not only creating an experiment and a hypothesis and testing things and getting results and then putting those results into words. It's not like that. I think the biggest factor is our own society."

As can be seen in Table 3.1all interviewees understood the scientific issues and the relationship between science and society.

Table 3.1. students attitude towards the NOS during the first semester (at the beginning and end of the fall semester 2015)

Students	Students' picture of science (Fall semester) First Interview, at the beginning of the semester	Students' picture of science (Fall semester) Second Interview, at the end of the semester
K	you just observe first, make your hypotheses, then researching and having some options and checking these options and staying with the best one and keep on researching with more people.	I used to think that science was super straightforward and science is true, regardless of whether you believe it. My picture of science is that it can be affected by religion, by society, where you live…. science is like messy and clumsy. Sometimes it's affected by politics or location, even the way of doing science.
L	We have a lot of technology that really helps science to progress. I think that science is all about questioning itself and trying to look for answers about everything around us and inside us and wanting to know more about everything.	There are many factors, like historical and social factors that affect the science process. and there can also be a bias, in terms of social class for example: not all social classes have access to knowledge, so they cannot give their contribution to science. Also, women, the gender bias, for many years, women weren't allowed to be part of scientific fields.

M	Science is the pursuit of knowledge, like the laws of nature...Like trying to understand how the world works and what's going on and 'why does it do that?', even if you're just pursuing this tiny little thing, you're looking at this 'what's happening?	Science isn't done in a vacuum. It always occurs in the context of social factors and history, and this truly shows us an embodiment of what happened historically in science, how social factors influence science.
N	Science requires a lot of studying. Your mind always must be thinking of what-ifs	Galileo Game opens your views to see like, because people think that, I find that
	and different theories how they can come together. Also, I guess you need to have great knowledge about the past of science, to kind of know the laws, you can't really, you can't just show up and say, 'well this might work'	what I thought coming into this that theories were based on this, were tested and this is what we know today, but the GG [Galileo Game] told you how wrong we were from the beginning. like the Church had a huge influence on what was right and what was wrong, and they didn't want to give in to what was right because it contradicted the Bible. So, all these cultural factors had a huge influence on what we believed was true, which is wrong! but today science is like, whoever comes up with a theory that they think might be right, gets a chance to prove it.

P	In terms of theories...I think scientists go from the things they know and have a question in their mind about something they want to know, and then develop a hypothesis from that.	Science is a much more complicated process than I thought! Because it's not only creating an experiment and a hypothesis and testing things and getting results and then putting those results into words. It's not like that. I think the biggest factor is our own society, and how the big influential thinkers have opinions. Galileo –a lot of things he said were correct but society didn't really let him express himself because his views were contrary to the views at the time. So that plays a big role in science.
O	Well, theories evolved, for sure through observation. That's a big part of it. Testing it out. Seeing where that leads you.	you have to be objective, you can't start experimenting, you have to like have your ideas on paper, your hypotheses, and obviously, don't, you could be biased you know, thinking 'Oh I'm pretty sure I'm going to get this result',
		put your ideas down, do your experiment and then see if it backs it up or not. It has to be systematic, you can't randomly do experiments 'I think I'm correct!' and just publish it.

Furthermore, the data collected from the participants in this project (group 1) was compared to the data collected from previous students in the same course (group 2).

The same interview questions were used to facilitate evaluation and comparison between the two groups of participants. The objective was to elicit whether different groups of students reveal the same approach to the same techniques of teaching. Having data of last year the students from the previous year provided some conceptual clarification for the research design as well. It helped me to refine my data collection plans. As you can see in the following analysis, I was able to show a same pattern in student's conception of science for both groups which added to reliability of my research. Group 1 students studied in the exact same course with the same professor and methods as group 2 students. Analyzing the two sets of data, I find that the same categories developed in the interview transcripts and students showed the same improvements in their understanding of the Nature of Science.

The result of the analysis is reported in the following order:

1) common themes though coding of the interview transcripts, 2) similarities between 2015-16 and 2016-17 participants' understanding of each construct.

Findings are classified into the following sections:

1. Social and cultural aspects of science
2. Tentative nature of scientific knowledge 3.

Subjectivity

Cultural and social influences on science

Many factors, such as historical and social factors affect the scientific process. In the context of this concept we examine whether students view the scientific enterprise as noncultural and non-historical, or as multicultural and history-embedded.

Four common sub-categories were extracted from students' responses:

1) The expectations of the culture determine what to study, scientists are motivated by social demands, 2) scientists are members of society, they are influenced by society (education and ways of thinking), 3) Religious background of scientific knowledge, 4) Gender and science.

Most responses showed a multidisciplinary view of science. Society, religion and gender restrict and direct scientists in considering what and what not to study and their personal biases:

Table 3.2. common themes found in 2015-16 and 2016-17 participants

Yes/ NO	Sub-categories	2015-16 cohort (out of 6 interviewed students)	2016-17 cohort (out of 6 interviewed students)
Yes	The expectations of the culture determine what to study; scientists are motivated by social demands.	2	2
Yes	Scientists are members of society; they are influenced by society (education and ways of thinking)	3	4
Yes	Religious background	4	3
Yes	Gender and science	3	2
No	Science is completely objective.	1	2

As seen in table 3.2 common themes were emerged in both groups. We see that most of the 2015-16 students are aware of sociocultural influences on science. Student K from 2015-16 stated that "now my picture of science is that it can be affected by religion, by like society, where you live."

Student L from 2015 discussed the religious background of science:

"Church was really involved in science in Galileo time and how the Church was really ruling science and deciding which theories were good and which weren't".

As can be seen in the table most of participants confirmed the sociocultural aspects of science in different sub-categories.

As an example of their responses, student Y from 2016 participants provided his own explanation of society influences on science:

"If you ask me if society influences science like Galileo time, I would say yes but nowadays it is not that obvious. So, you might say no but still, there are some influences of society but it is not that obvious and that's a thing I really didn't know before this class."

Tentativeness

Popper (1968) and Bromme and Goldman (2014) consider that uncertainty and tentativeness are characteristic for empirical results. Ioannidis (2006) states that "Instead of solid knowledge, we should get used to the notion of tentative information". Understanding tentativeness also means to comprehend that findings may contradict each other or become obsolete when more reliable findings occur (Sinatra et al., 2014).

The results of both studies demonstrated that participants in this course detected the tentative nature of scientific knowledge and students no longer see science as an absolute truth.

Four common themes were emerged from students' responses:

1) a new phenomenon could show up with the help of advanced technology, 2) changes in science could occur due to the inability of a scientific theory to explain new knowledge, 3) humans' ideas changes, 4) fundamental theories (such as Newton's laws in mechanics) will never change in their area of application. (extending the area of application as in special relativity and quantum mechanics could result in new theories)

In the interviews, students explained their ideas about how science progresses and what could possibly influence scientific progression.

Table 3.3. Students' ideas about how science progresses. (common themes found in 201516 and 2016-17 participants)

Change/ No change	Sub-categories	2015 participants	2016 participants
Change	a new phenomenon shows up with the help of advanced technology	4	3
Change	the inability of a scientific theory to explain new knowledge	3	4
Change	humans' ideas change	4	3
Change	No reason was provided	2	1
No change	fundamental theories would be the same	1	0

As can be seen in the table, 5 out of 6 participants in 2015-16 and 6 out of 6 students in 2016-17 think that scientific knowledge is tentative. After the first semester, only one student from 2015-16 participants still see science concrete and perfect.

In giving examples for students' responses, Student O from the 2015-16 participants brought an example from the Aristotelian and Galilean theories and explained the tentative nature of scientific knowledge:

"Relating it to the Aristotle / Galileo case, he had this theory that the earth was at the center of the universe and then here comes Galileo who says well no, the earth revolves around the sun. I think there was more not proof, support, we can't use the word proof, there was more evidence supporting his theory, so I guess that kind of replaced...and obviously now, since we've been to space, we know that he was right in the end, so, I think either just having more evidence or with time, when we get more technology to actually see ourselves what it is."

An example from 2016-17 participants, student JO, explained how human's scientific progress depend on the culture they live in:

"depending on the culture we are in and what religion we have and other social factors. So, maybe what we believe here in North America is very different from I don't know… like Asians maybe think different in that culture. So, how we approach stuff is going to be also different."

Student SE discussed tentative nature of science in terms of technology advancements and how it helps us to approach scientific phenomenon in a different way:

"we have new technology that allows us to be maybe more precise and makes us realize that maybe: okay! actually it's not right and then people can go back to the drawing board and figure out what's really happening."

Data analysis showed that most students from both years agreed that no scientific theory can ever be considered completely proven and they are always changing and evolving.

Subjectivity

Scientists do not conduct absolutely objective observations, do not reach objective conclusions and do not evaluate new evidence objectively (Lederman and Abd-El-khalick, 2002). Just as students' interpretations of observed phenomena are influenced by their beliefs, values and previous knowledge, so too are those of scientists (Lederman, 2007).

Based on the interviews with participants in both years and as can be seen in Table 3.4, I concluded that most of the students understand the subjectivity of science.

Two common sub-categories were extracted from students' responses:
1) Science is influenced and driven by the presently accepted scientific theories and laws. The development of questions is also based on current theory, 2) Personal subjectivity is unavoidable in scientific process.

Table 3.4. Subjectivity of science

Subjective/Objective	Sub-categories	2015 participants	2016 participants
Subjective	Science is influenced and driven by the presently accepted scientific theories and laws. The development of questions is also based on current theory.	4	3
Subjective	Personal subjectivity is unavoidable. (Personal preference)	3	3
Objective	Science is completely objective.	1	2

In seeking to account for subjectivity of science, 5 out of 6 students in 2015-16 and 4 students out of 6 in 2016-17 felt that science is dependent on scientists' background, their levels of education and their personal preferences as well as exterior influences such as currently accepted theories.

Students confirmed that observations are not completely objective and can be affected by related scientific theory. They explained that scientists always learn basic knowledge and then they try to build upon it, which can make science subjective. Student L discussed an example on how presently accepted theory influences science:

"Most of the students choose their major and then in their masters and PhD, they are working on one of the accepted theories and they don't cross links with the other ones."

Student M from the 2015-16 participants also mentioned the exterior biases in scientific knowledge:

"you're shaped by the knowledge we're already aware of. You'll think 'maybe this mechanism is like that mechanism'. You won't be able to come up with completely off-the-wall theory."

Student MA from the 2016-17 participants explained how scientists' personal biases make science subjective:

"Well, I think we are all human and we all have like biases and so even with our own research, we can't be completely objective and so where Aristotle was arguing about his research and he didn't want to see the other facts or the other discoveries that were happening at the same time. I think that if you've been working on a project or on a theory for like 20 years, I think it can be hard to… like if someone comes up with a different idea or something that rejects your theory, I think it can be hard to switching and be like: okay! I was wrong because you've been putting and investing project. So, I think just so much energy, time and money for that project. So, I think just personal biases and social factors still have influences as much as it did in those days." As can be seen the result of data analysis showed that both groups of participants from 2015-16 and 2016-17 felt that there is an element of subjectivity in science.

3.3. Data analysis (Second semester)

Table 3.5. changes in students' attitude towards NOS throughout the course (Interview summary)

Case Studies	Students' views about how theories evolve (First interview)	Students' views about how theories evolve (Second interview)	Students' view of science (First interview)	Students' view of science (Second interview)
F	I feel like science would be always the same. I don't see it in a different context or different rules.	Scientific theories have to go through that phase of resistance … Like there's a crisis and you have those big debates going on. … You have	If you want to learn science you have to take a lot of science courses and do a lot of problems. … I feel for science you rely on your	Although you think science is perfect, you can understand their flaws. It is not just like: okay! Here is a question and I solved it and this is the answer

		to have tribulations like a paradigm shift.	teachers and your books.	that I want. … from the historical perspectives, you can see the other influences.
G	They (scientific theories) can definitely change. We just have a lot of models, right? … When you find something that does not fit the current model … then you have to find a new model to work for it.	Whenever a new phenomenon shows up that the old model can't predict or explain and there's a lot of evidence for that new phenomenon that becomes important people can't ignore it anymore …, we create a new model that takes that into account. … it really is less a throwing out of old information it's more creating a new model that can accommodate for things we never saw before.	Science is a collection of knowledge that people built together sometimes tearing each other down but also building each other up to come to this agreement on what people think about how the world works.	Science isn't as perfect as I expected it to be. I see it as much more socially implicated field before I saw it as an objective mathematical field now I realized, it got a lot of influences in more social aspects like history philosophy political and religion as well.

H	we used to go with Newtonian physics but nowadays we know the theory of relativity because at certain points Newtonian physics stopped working. … that	I think the process of changing theories is really slow moving and you don't really acknowledge it while it happens. When you realize that they're quite a	The opportunity to do research and not spent my life in cubical. Like, be able to find stuff out like enjoy myself in my work and that kind of things. I see science more	Science is a hugely multidisciplinary kind of combination of knowledge. I used to just see science as like this course load in school. It is a lot of

	might have more with all laws of physics not being complete. So, yes. I think science could change. I don't really know how it could change.	few flaws to this Theory and afew people come up with a few different theories but eventually we put together to form a new paradigm that's slowly replacing with the old one mainly through a process of death because all of the scientists that used to believe in the old Theory and who were like hard into it end up dying or just retiring and all the new scientists that have a new Viewpoint and a new way of looking at things and who aren't already incredibly biased, they sort of taking over and their theory take over as well.	as opportunities I guess.	information about a lot of different fields that while being related to each other kind of aren't.
I	People have learnt things in university in the past that they	Once your new ideas out and then scientists start reviewing	A lot of it is pretty straightforward. However, in	People coming to University who think science is all this

	realize they're wrong and obviously, they move forward because like life isn't perfect you know that like we are trying to get closer and closer to the truth but at the end of the day like it's okay, it's possible to step back and realize it's not entirely right this was wrong and then maybe like relearn it and do something different.	these things they start realizing ok! it works and they start realizing that maybe this is true and at first everybody just squash your theory. People really have to assert themselves really push for what they believe in	social science, there is a lot of crap in between. Maybe sometimes in science too but I think more it affects more social science. some classes it's solely the teacher. some classes it's I mean… obviously, it comes back to you like you have to be resourceful and you have to be able to pick and choose but I feel the best one is definitely the knowledge from the teacher because it's a lot more efficient and learning like if you go to class and take down what the teacher says and study	and you learned all these, a lot of the books, they learn about some of the techniques but then when they come to the real world they realize … it's kind of tough. … all the extra stuff that people don't really talk about …. It's so broad like lots of research, lots of steps involved like lots of people, where the funding comes from and it's like a multidisciplinary thing.

J	We like to think that everything is very empirical and systematic and you do the experiment and you see the results and then you have like a	When they [scientists] brought up the scientific method, specific to certain things. there's less of this Universal explanatory	Science is a mix of things. One of our assignments with the class was … a map of what is science? And so, we had things like … all the fields that	Before doing this class, I thought science was clear and it was direct and there is no bias in any way and you would get to the truth and that's the
	fact or like good knowledge.	power where it's so vague that it	you can do science in, so	only thing that would

	…There are other influences like the pressure of funding agencies. So, basically you do research and you can analyze them and that's it but I don't think it is that clear.	can fit into pretty much anything … because other scientists are more critical of what they read and what they look at, theories are more specific and more testable verifiable than some of the previous theories.	biological fields or … physics, chemistry.	come out of scientific research but all the readings that we done and discussions and debates that we had open my eyes to see that it wasn't as clearcut as I thought that there are a lot of other things that come into science. it's not as empirical as we think it is and a lot of underlying things like social factors like the politicsof a science thatalso has impact on outcomes but yes …I was going to say scientific way but more empirical way of doing research.

1. Student F

In the first interview, in response to the question on how scientific knowledge evolves, she stated that science would be always the same and she can't see it in a different context:

"I think the fundamental science would be the same, no matter who we are. I feel like science would always be the same. I don't see it in a different context or different rules."

In her reflective writing assignment student F explained her understanding of a Kuhn paradigm

shift:

“The idea that scientists need to have a paradigm to discover things seems off. Shouldn’t it be possible for someone to just decide to explore even though this is not the norm something that piques their curiosity and still come to the same conclusion as someone who would have encountered a problem to reach that conclusion.”

I believe that she critically evaluated Kuhn’s point of view and challenged the idea of a paradigm shift.

However, on the last day of the course, in responding to the question of how scientific theories evolve, she had changed her attitude about the NOS and explained that science changes in the manner of a paradigm shift as described by Kuhn. She states that “scientific theories have to go through that phase of resistance pretty much like in Darwin and Galileo. … you must have tribulations kind of like a paradigm shift. There’s a crisis and you have those big debates going on. So, it’s like a Circle event that happens I feel like it’s a pattern but the way it plays out won’t necessarily be the same in both. I feel like with Galileo he was in court but it’s pretty much the same thing that happened with Darwin with just like scientist debating.”

She also showed an impressive change in her conception of science. The pre-interview transcript showed that she thought for science she should rely on her teachers and books and what is presented to her. The post-interview showed that she didn’t think science is straightforward anymore:

“Science is not just like: okay! Here is a question and I solved it this is the answer that I want.”

She also confirmed that:

"Before I just thought of it like going to school but now I have a different perspective. It is not as simple as you think. You think that you just do science but actually, there are many factors." She came to realize that science has a multidisciplinary nature as she also explained that there are so many little things that influence science which we need to consider.

2. Student G

In the pre-interview, student G explained that scientific knowledge always changes. Using the example of Dalton's atomic model, she explained that all theories are not necessarily true in every aspect and that is why they go through changes. She believed that when we find something that really doesn't fit the current model then we have to find a new model to explain it and that is how scientific theories progress.

She also considered science as a collection of knowledge:

"Science is a collection of knowledge that people built together sometimes tearing each other down but also building each other up to come to this agreement on what people think about how the world works."

In the post-interview, she explained that science is influenced by so many things such as culture, religion and society. She also stated that these influences drives what kind of science should be done and what kind of results are acceptable. She confirmed that before this course she saw science as an objective mathematical field: "before I saw it as an objective mathematical field now I realized, it got a lot of influences in more social aspects such as history, philosophy, politics and religion as well."

In summary, based on the pre- and post-interviews I included that the course helped to change student G's conception of science. She initially saw science as a collection of facts but at the end, she was aware of many factors that influence science:

"I really liked the pure philosophy when we looked at Kuhn and Paradigm changes and Popper when see that these are just induction and objectivity or something that were kind of brought to science and it didn't necessarily come naturally. It was more we decided that this was what science meant but … we still follow … [the] inductive model and this objectivity kind of models that they have … maybe science isn't as perfect as expected to be. So, it's really changed my views."

Her response as to how theories come about followed that of Popper.

3. Student H

During the pre-interview, student H explained when older theories, which are not complete, stop working then a new theory takes the place. He was not sure about how the process is made. He also stated that eliminating the human aspects of science helps science progress.

In the post-interview, he mentioned that the process of changing theories is slow moving and eventually a new paradigm slowly replaces the old one. Theories change in the manner described by Kuhn.In the post-interview, he also stated that he used to just see science as a course load in school. Moreover, he used to understand science in a very straightforward manner: "Well, before for me learning about the science involved just opening up a power point and reading sort of basic facts. Now I have a more practical view of what learning science is rather than sort of theoretical view."

He clarified that the course helped him to understand that what a teacher teaches is just a theory and it is not an "absolute truth".

During the post-interview, student H mentioned that he thinks society can affect science and he also provided a recent example related to his field:

"I definitely think that society can affect science cause if we look at more recent examples like how Russia affected its genetics and biologists and force them to go with inheritance law instead of Darwinian evolution. So, like [in] Galileo times society always plays a massive role."

4. Student I

In the pre-interview, student I explained that a lot of science is straightforward except social science. In answer to the question of how theories evolve, he stated that through experimentation we find flaws in the previous theories.

In the post-interview, he explained the Kuhnian point of view that when new theories come about, there will be a resistance from the scientific community as happened in the time of Galileo.

When I asked student I to explain his picture of science in the post-interview, he specified that science is not only coming to school and learning certain books and techniques. It is much more complicated in in the real world In the post-interview, he also explained that the course helped him to understand that science is a multifaceted entity:

"It is not just science, it is a lot of stuff around it too. You know all the extra stuff that people don't really talk about it all that much; more the issues, more the implications, and certain things. It is all that things around it that involves in science and there is always going to be. It's so broad like lots of research, lots of steps involved like lots of people, where the funding comes from and it's like a multi-disciplinary thing."

5. Student J

During the pre-interview, student J explained that science doesn't work in an empirical and systematic way:

"I think we like to think that everything is very empirical and systematic and you do the experiment and you see the results and then you have like a fact or like good knowledge, I think sometimes it can differ from that track, I think mainly like research, systematic things though, there are other influences like the pressure of funding agencies. So, basically you do research and you can analyze them and that's it but I don't think it is that clear."

Her response in the pre-interview was that experiment leads to theory but other factors such as personal biases also play a role.

In answering the question of how theories evolve in the post-interview, she said:

"When they (scientists) brought up the scientific method, I think they are more specific to certain things. There's less of this universal explanatory power where it's so vague that it can fit into pretty much anything. So, I think when scientists are more critical of what they read and what they look at, theories are more specific and more … verifiable than some of the previous theories."

In the Darwin game discussions towards the end of the course, she also made a good connection and used Bacon's argument to challenge her classmates:

"So, you said that Darwin's theory is scientific because he made a bunch of observations and constructed a theory based on this observation but that is not exactly a scientific method. The Scientific method requires prediction. You have to test these predictions with experimentation

that can be repeatable. Could you please explain how can we test the theory of evolution through experimentation?!"

In summary, based on the pre- and post-interviews with student J and also analyzing her attitude towards class discussions, I concluded that this student's views of science didn't change but she was able to give a much clearer exposition of her Baconian views.

3.4. Analysis of non- interviewed students

To show that case studies were representative of the whole class, I analyzed data collected from non-interviewed students.

Four students, 2 female and 2 males were analyzed. The logic sampling strategy. Students were picked from different genders and different majors. Two sources of data collection were used for non-interviewed students. First method of data collecting was direct observation since observational evidence is often useful in providing additional information about the topic being studied. Second source was students' assignment. The analytic technique used on data collected for these students was pattern matching. Using pattern-matching compares an empirically based pattern with a predicted one. (Trochim,1989). I find the patterns coincide with interviewed students which helped this study to strengthen its internal validity.

1) Student A

Analyzing this student assignments, I could find some changes in her ideas about theory evolving as she wrote in one of her assignments that the Popperian point of view touched her and made her think differently:

"I'm sad to say that I only recently learned that in order for a hypothesis to become a theory, it must undergo tests that attempt to disprove it (not only tests that attempt to prove it right). While

this might not overtly seem very important, I have to stress the fact that this means that I didn't truly understand the scientific process, even after having studied it for several years. This lack of understanding on my part has undoubtedly led me to believe that different theories were scientific even though in hindsight, it is blatantly obvious that they aren't. However, by using the criteria outlined by Popper, I can easily tell that Marxism (which I was taught in my first semester in CEGEP) isn't actually very scientific, given that the theory behind it is vague enough that it can't be disproven (a hallmark trait of pseudo-scientific theories as outlined by Popper)."

Also in one the class discussions she explained Newton's theory and pointed out that through falsification we can prove this theory is scientific:

"It must be possible to prove a theory wrong through very specific tests. For example, Newton's theory of gravity states that objects with mass must be attracted to each other. This theory therefore states that objects with mass can't repel each other, in effect it "forbids" them from repelling each other. Thus, in order to prove this theory wrong, one would simply have to devise an experiment in which objects with mass can be observed to repel each other. Due to these characteristics, Newton's theory of gravity can be considered scientific."

Based on this information I concluded she has a Popperian point of view at the end of the second semester. This student didn't get to be interviewed but the data collected from class observation and her assignment revealed her attitude towards the NOS.

2) Student B

In the first paper assignments this student uses a Baconian point of view as she wrote:

"I think scientists are researchers who strive to understand nature. They are unbiased and that they are willing to contemplate different theories in order to find the "truth".

A reading of student B's writings made on the last days of the course indicates that student views became clearer as he found out about different philosophers of science. Yet he didn't inevitably change his views but they became more expert like. In one of the discussion he mentioned in science, we never fully understand a concept; we make correlations between observation and what we already know which is a Baconian perspective towards the NOS.

He also criticized the Kuhnian and the Popperian point of view and felt that these approaches cannot fully define a scientific theory:

"While I cannot say that Popper has solved the problem of induction simply through noticing that it exists, I do believe that his criteria for what is and isn't a scientific theory will aid in clearing up this problem. As the saying goes, "the first step to fixing a problem is finding it".

In my opinion Popper's solution for understanding the character and development of science is invaluable if it is properly used. Kuhn referred to the fact that some scientists might be temptedto modify their experiments and "cheat" in order to prove their theories right. I believe it's safe to say that these theories are not true science and tend to fall into the category of pseudoscience.

Thus, even though these theories might pass Popper's criteria, due to the fact that they are effectively wrong (as a result of improper observations on the part of the scientists), they still cannot be considered scientific. Thus, I believe that we must ask ourselves what constitutes true science, for neither Kuhn's perspective nor Popper's criteria accurately answer this question.

By comparison of his early and last papers, it's fair to say that his ideas about the conception of science become clearer although her attitude towards the NOS did not changed.

3) Student C

Most of his class discussions earlier in the semester showed that he had found out the important concepts covered in the class, but the explanations about those concepts were unclear. I bring an example of his discussions in early classes:

"I think general knowledge is very abstract while scientific knowledge is more science. Since there is science in it, it is more science. General knowledge is more graspable. So, maybe my knowledge is completely different from some one else's knowledge but, since it's science and this is what it is, we may have same scientific knowledge."

His later discussions were more understandable. In a topic in one of the last classes about hypnosis, he said:

"Hypnosis is both experimental procedure and an object of study. The problems around hypnosis in my opinion stem from the fact that it is impossible to say if it is 100 percent science or 100 percent pseudoscience. More research has to be done before hypnosis could be considered a scientific phenomenon"

So, he is trying to analyze the phenomenon of hypnosis using Popper scientific method. He also gave a good analysis of Popper's philosophy of science:

"In this discourse Popper attempted to explain away the difference between science and pseudo-science. In order to do this, he focused on the key defining features of scientific theories, namely scientific theories must have a possibility of error; it must be possible to prove the theory wrong through very specific tests. Another defining feature is that the theory must forbid certain things from happening."

The above analysis showed that his concepts of science improved during these two semesters.

4) Student D

Early in the course his writings were more descriptive than conceptual. Later on, he picked up some important concepts, which were covered in the class. In the sixth week he talked about the subjectivity of science and its influences on scientists' researches and he also tried to explain its importance in the field of physics. He wrote:

"If you were to ask several different people what they thought scientists were like, the consensus would likely be that scientists are unbiased in their researchs. For example, when doing research, it isn't rare to see a scientist fuss with his tools and equations in order to obtain the results he expected from the start, kind of like how a student might "accidentally" change a "+" to a "- "in an equation in order to make the math come out on a calculus test. Nor do scientists easily give up the paradigms they rely on to make their theories."

In this assignment he used a very good analysis of Kuhn philosophy of science. He is referring to scientist's paradigms in a manner of Kuhn.

Moreover, some important questions came to his mind that helped him to expand his thought further. For example, upon reading Mermin's *The Golemization of Relativity* in the eighth week he asked:

"If science one day truly does 'golemize', will we be able to stop it or will we be dragged along with it until our inevitable end?"

In the submitted course dossier, he explained this point:

"This is not to say however that there exists no common ground, it is true that biases on the part of others can halt the progress of 'true', progressive science for years (just look at what happened to Galileo, because scientists of the church disagreed with him, he was placed under house arrest for the remainder of his life and told that he could not continue publishing his 'heresy'). Thus, while it is true that there can be a problem of golemization in science, it simply isn't as prevalent as Collin and Pinch seem to want their readers to believe."

In conclusion, his thinking levels about concepts of science improved.

3.5. Overview

This section is the overview of the previous sections (3.1,3.2, 3.3, and 3.4) Table 3.6 is the summary of the analyzed data of the interviewed (First-semester) students; Table 3.7 is the summary of the analyzed data of the interviewed Students (second semester); Table 3.8 is an overview of the analyzed data of the non-interviewed students. This section will discuss the ways the student-centered teaching improved the students' understanding of NOS during two semesters by comparing the cases.

Table 3.6. A Summary of the Analyzed data of Interviewed Students (First Semester)

Case	Earlier in the semester	Later in the semester	Students' personal experience of the course	Methods that students' find helpful
K	She saw science as an objective entity with straight forward methodology.	She explained that scientists are motivated by social demands. they are	The course challenged her to think things she has never thought before.	RW papers allowed her to analyses how science works. By analyzing the works of

		influenced by society.		different authors, she got involved with material of the course.
L	He saw science as a general wondering and trying to look for answers about everything around us.	Discovered many factors, like historical and social factors that affect the science process.	She explained in this course it wasn't really about memorizing, it was more like creating. It really helped her to understand see how scientists made their discoveries.	Class discussions, Galileo Game helped her a lot in order to understand how science works.
M	Saw science as the laws of nature and trying to understand how the world works.	Being aware of socialfactors and embodiment of historically influences in science.	He thought the course was beneficial for him Because students shouldn't spend all their time learning theorems or learning laws. . He thought that philosophy in general is very important to every student.	Galileo Game helped him rewriting and researching the subject matter all the time and make him prepared for the class.
P	She explained science is only about hypothesis and experimenting.	She was aware of the fact that expectations of the culture determine what to study.	Despite other courses, this course wasn't about memorization. It was about making links, researching and understanding.	RW papers helped her to be prepared in advanced for the class and helped her to be highly engaged.

O	Saw theory evolving through observation.	Understood the biases in science progress journey.	*learning about history of science was very useful to understand how*	RW and GG were very useful since they
			science works and how theories evolve.	helped her to interact better.

From Table 3.6, we see that the students O and P and K found weekly RW assignments helpful. They did not miss any RW during the semester. We can see at the end of first semester, they were aware of subjectivity of science and effects of society on science. For L and M, the Galileo Game was very useful, based on analysis they no longer thought science was straightforward and they understood how religion can affect the progress of science. Most of the students understood that science is not just the matter of random experimentation and that science is a complicated process. By comparing their interview transcripts (section 3.2) we see that their conception of science improved during the first semester.

Table 3.7. A Summary of the Analyzed Data of Interviewed student (second semester)

Research Questions	Case	Students' Approach
Does studying Nature of science in a student-centered	F	She had changed her attitude about the NOS and explained that science changes in the manner of a paradigm shift as described by Kuhn.
classroom change students' conception of Science?	G	At the end of second semester Her response as to how theories come about followed that of Popper.
	H	he thought that the process of changing theories is really slow moving and eventually a new paradigm slowly replaces the old one. Theories change in the manner described by Kuhn.

	J	This student's views of science didn't change but she was able to give a much clearer exposition of her Baconian views.

From table 3.7, we can see that some students changed their attitude towards the NOS. Student Some students did not change their views but they were able to give better explanations of their conceptions of science.

Table 3.8. A Summary of the Analyzed Data of Writing Products and observational documents (Non-Interviewed students)

Research Questions	Case	Students' Approach
Does studying Nature of science in a studentcentered classroom change students' conception of Science?	**A**	changes in her ideas about theory evolving were found. She has a Popperian point of view at the end of the second semester.
	B	His ideas about the NOS became clearer although her attitude towards the NOS did not change.
	C	His concepts of science improved during these two semesters. He analyzed the progression of science using Popperian philosophy.
	D	His thinking levels about concepts of science improved although there were no changes in his attitude towards the Nature of Science.

As can be seen in table 3.8, the data analysis on non-interviewed students agrees with the interviewed students. In this part of research observational evidence was useful in providing additional information on the non-interviewed students.

The overall results and discussion showed that the student-centered classroom helped the students to improve their understanding of the NOS. This study should be helpful for science educators in designing their science courses for first year science students. Also this study gives instructors information about how students can go through conceptual change and become an active learner.

Chapter 4: Conclusion and Summaries

Too few science programs require any coursework involving a deep and robust understanding of the NOS (Backhus and Thompson, 2006). Many articles in the journal Science and Education consider contributions to teaching and learning about the NOS. However, in the majority of these studies (section 1.5.), the authors' claims about adequately and deliberately teaching and learning about the NOS to science students are not backed up by methods of student-centered teaching and qualitative data to help us know whether student-centered classrooms- specifically what educational methods- actually helps learning, or, if it does help, how it helps and what we need to do to make it an effective learning activity.

Answers to such questions are helpful for both educators, in terms of guiding future students, as well as researchers, who seek a deeper understanding of the processes involved in

implementing such activities. In this study we conducted interviews and combined the qualitative analysis of the interviews, student writing products and classroom observational data following a qualitative research approach, as recommended by Corbin and Strauss (2008) and Packer (2010)) to examine these research questions. We also studied students' understanding of NOS to explore whether student-centered teaching is helpful to achieve effective NOS learning outcomes.

This thesis establishes three main items:

1. The characteristics of student-centered teaching and educational methods that can be used to help students accommodate the course material.
2. Participants' improvement in understanding specific aspects of the Nature of Science.
3. Improvements and changes in students' philosophical attitudes towards Nature of Science.

4.1 Results of Our Studies

4.1.1 First part of the project

The first part of our research project focused on students' perspectives about different features of the NOS and how their views can be changed in active learning. We interviewed six students who completed SCOL 270 in 2016-17. In order to add to the credibility of the research, we also assessed the interviewees' writing products and the writing assignments. Based on the interviews, we found the specific aspects of the NOS that improved in students and classified these aspects into three broad categories. First, generally students agreed science is continuously changing due to using advanced technologies. Students accepted the tentative nature of science and had a strong view that scientific knowledge progresses. Some other students felt that scientific knowledge does not change. For those students, theories such as Newton's gravitation law do not drastically change but are refined to be more accurate. The data collected from the

participants in this project (group 1, 2015-16) was compared to the data collected from previous students in the same course (group 2, 2016-17). We considered 6 students in 2015-16 and 6 students in 2016-17. (Table1) To blend the data from participants from both years the same questions from the end of the first semester in the 2015 -16 course were used in the beginning of the second semester of the 2016-17 course. The research project was overseen by a senior researcher for both courses. Both courses were taught by the same instructor, who was not part of the research team and who taught the course in the identical manner both years. Transcripts of both years were analyzed using open coding methods. Based on the analysis, we found a very similar result in both years. (see the following charts)

For example, 4 students out of 6 participants in group 1 and 3 students out of 6 participants in group 2 showed progress in the first sub-category (changes in science due to advanced technology) of tentative nature of science (first theme). From this we can see a trend that shows students of both years realized tentative nature of science.

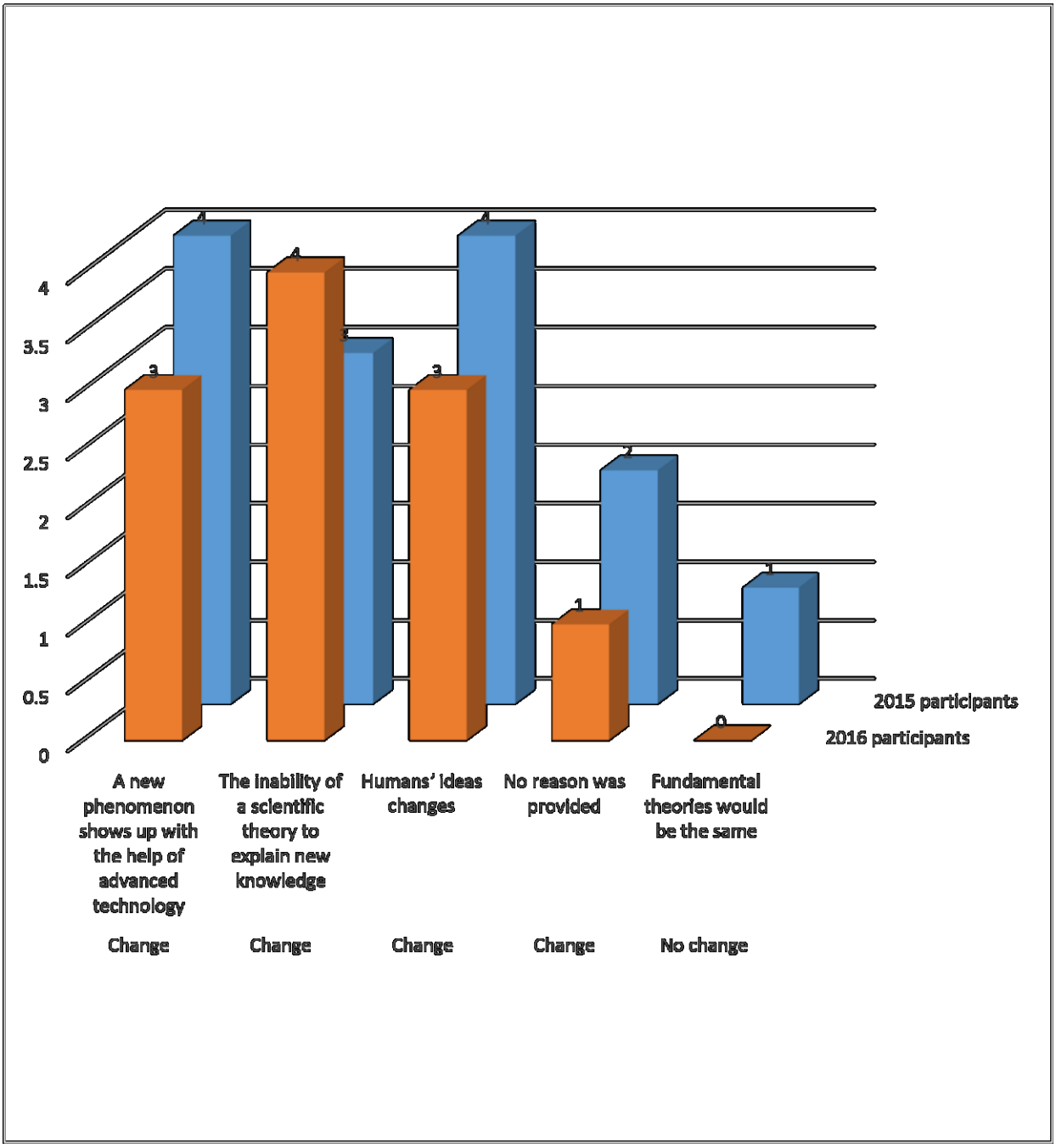


Chart 1. students' understanding about tentative nature of science (comparison between 2015-16 and 2016-17 participants).

Second, on the topic of subjectivity of science, the students felt that science is influenced and driven by the presently accepted scientific theories and laws and personal subjectivity is

unavoidable. In particular, when data were not solid enough, students felt scientists filled in gaps from their own assumptions and imagination. You can see the comparison between participants of 2015-16 and 2016-17 in the following chart. Students from both 2015-16 and 2016-17 showed considerable change in each sub-category of subjectivity of science. For example, 3 students out of 6 in 2016-17 and 4 students out of 6 in 2015-16 showed progress in the first sub-category (science is influenced by currently accepted theory in scientific society) of the subjectivity of science (second theme).

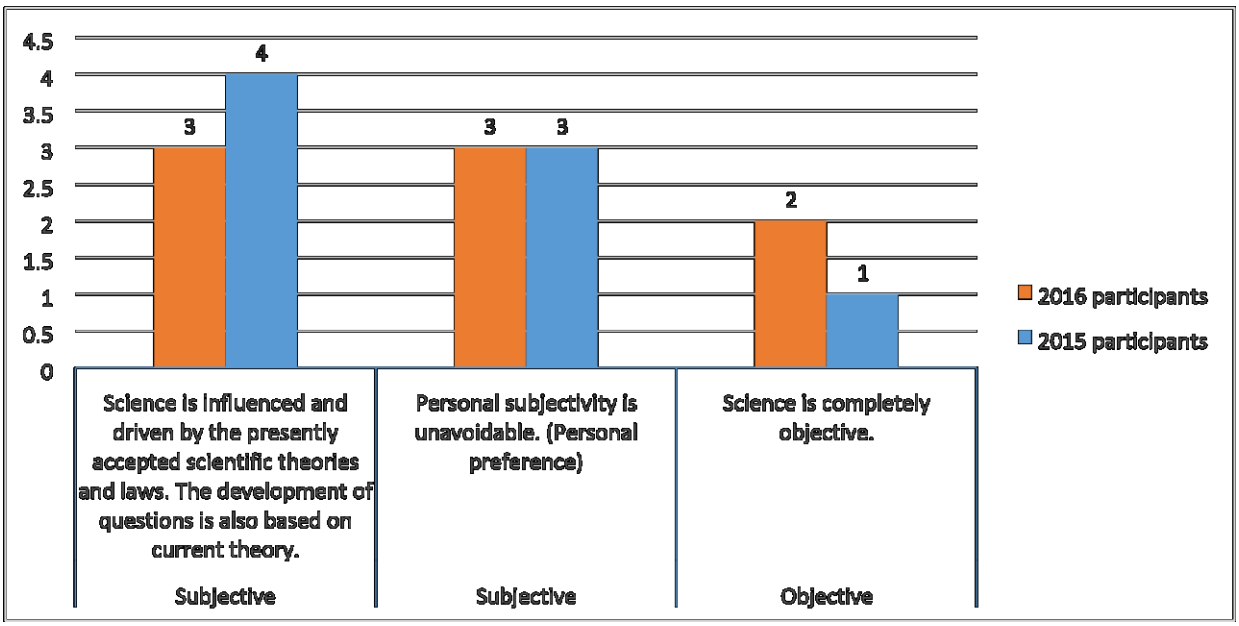


Chart 2. students' understanding about subjectivity of science (comparison between 201516 and 2016-17 participants).

Third, the majority of the participants agreed there was mutual interaction between science and society. Some students thought politics and religion have resulted in abuse of scientists and science for example Galileo and Darwin. They also discussed the influence of

society on scientists as members of society; Participants of both years showed a good understanding of the socio-cultural aspects of science.

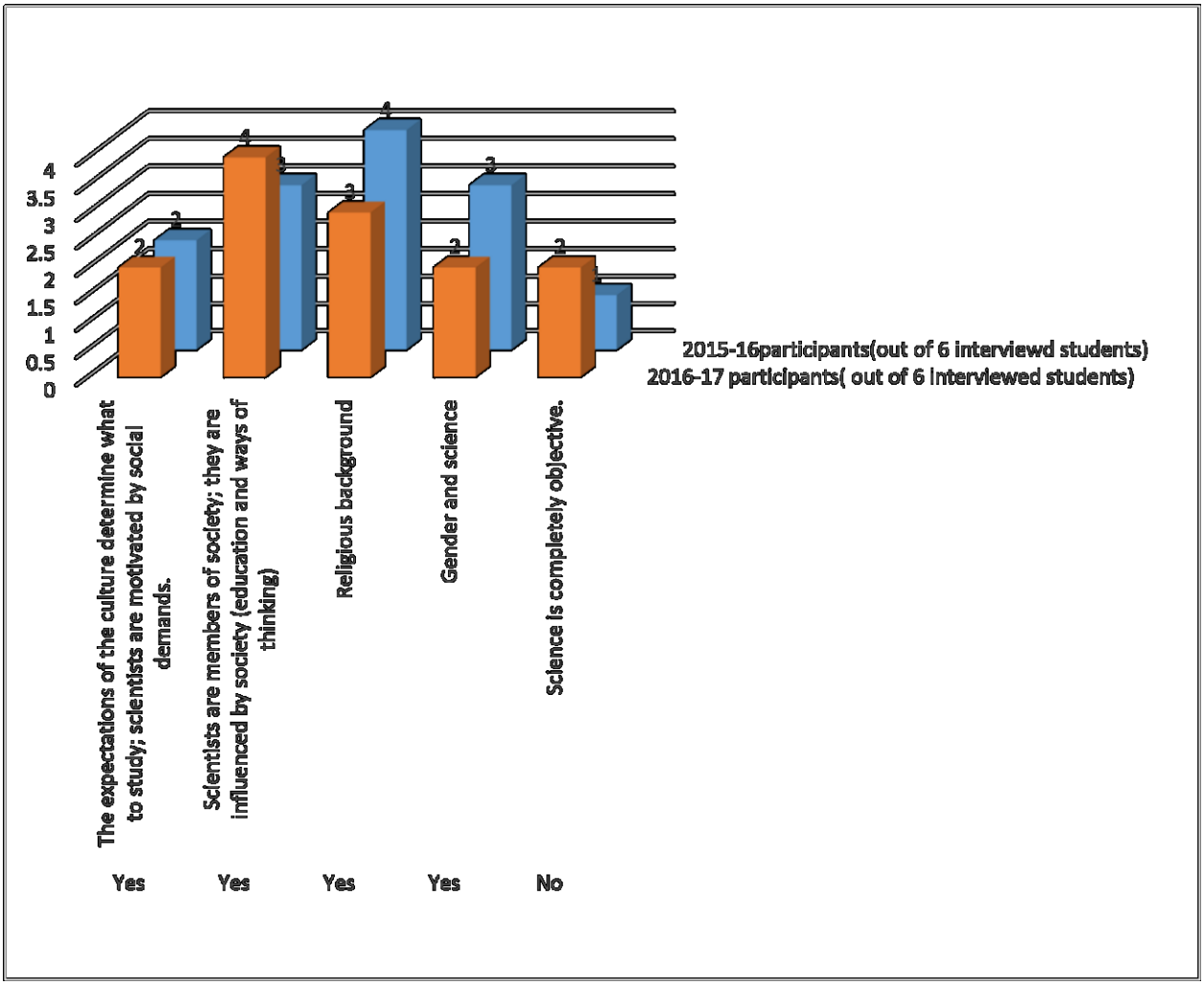


Chart 3. students' understanding about socio-cultural aspects of science (comparison between 2015-16and 2016-17 participants).

By evaluating students' reflective writing products, we found that in the beginning, students saw science as very straightforward and set in stone. In general, student writings became clearer and more understandable by the end of semester. Moreover, students' understanding of

The NOS changed.

4.1.2 Second part of the project

Kalman (2002, 2010) conducted a case study to find out changes in students' attitude towards the NOS. In this project students were divided in different groups and each group of students studied one of four modern philosophers of science. Each group of students discussed their conception of what the philosophers would think about the course matter. He found the class project had a strong influence on students' views of the NOS in that many students changed their views about how theories evolve. This conclusion is very broad and based on a class project assignment. To extend Kalman's studies on the NOS we conducted multiple case studies on a course about historical, philosophical and social aspects of science. This course was taught using studentcentered instruction. We measured the effects of this course on students understanding about the NOS. We found impressive changes in students' conception of science and from there we conclude that using student-centered instruction which (as discussed in section (1.2)) is effective in teaching the NOS to science students.

The second part of this project focused on getting students to understand the NOS by considering historical material in relation to modern philosophers of science. Based on interviews and an examination of students' writing products, we found improvement in students' perspectives on how scientific knowledge evolves and significant changes in students' philosophical approach towards the NOS. We classified the points mentioned by the interviewees that corresponds to different philosophical attitudes towards the NOS into three broad categories.

First, Karl Popper's philosophy of science which uses modus tolens as the central method of disconfirming, or falsifying, scientific hypotheses. Through open coding analysis, we could show some students get closer to a Popperian point of view after the second semester.

Second, we found themes in data collected from participants which are followed by Baconian points of view. Bacon's philosophy is a more empirical view about scientific knowledge and it suggests scientific ideas develop by induction from experiment. The philosophy of Francis Bacon dominated physics from the beginning of the seventeenth century to the end of the nineteenth century. The emphasis was on observation and induction.

Third, we could show some students' attitude towards the NOS is changed to the one proposed by Kuhn. On the third group, the Kuhn group concluded that a new theory was developed following the small paradigm shift that occurred when scientists abandoned previous theories.

Fourth, the category of students who did not change their philosophical approach of science but their conception of science become clearer and more coherent.

It was clear that the course had a strong influence on students' views of the NOS in that students changed their views about how theories evolve.

4.2 Future Directions

This research helped us find out about effective methods of student-centered instruction. Traditional styles, which are based on recitation and memorization techniques, fails in delivering abstract and less sensible concepts of NOS. As follow-up research, I suggest talking to the course instructor to discuss other possible activities that we can implement to help students gain a better understanding of the NOS.

Since we found that there is a change in students' philosophical approach to theory further research could explore the reasons for such change.

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Appendix A

Invitation to participate in a research study

INFORMATION AND CONSENT FORM

Study Title: Teaching Nature Of Science(NOS) with student-centred instruction

Researcher: Fereshte Heidari Khazaei

Researcher' s Contact Information: freshteh121@gmail.com ,Phone: 514 625 1077

Faculty Supervisor: Dr.Kalman

Faculty Supervisor' s Contact Information: calvin.kalman@concordia.ca

You are being invited to participate in the research study mentioned above. This form provides information about what participating would mean. Please read it carefully before deciding if you want to participate or not. If there is anything you do not understand, or if you want more information, please ask the researcher.

A. PURPOSE

The purpose of the research is to explore students' understanding of Nature Of Science in an innovative pedagogical context.

B. PROCEDURES

If you participate, you will be asked to be observed by an investigator throughout class sessions at the winter semester and also your reflective writing, and course dossiers assignments will be examined by the investigator. All data collected will be used exclusively for the purposes of the study.

C. RISKS AND BENEFITS

This research is not intended to benefit you personally.

D. CONFIDENTIALITY

The information gathered will be identifiable. That means it will have your name directly on it. We will protect the information by the research team. We intend to publish the results of the research. However, it will not be possible to identify you in the published results.

F. CONDITIONS OF PARTICIPATION

You do not have to participate in this research. It is purely your decision. If you do participate, you can stop at any time. You can also ask that the information you provided not be used, and your choice will be respected. If you decide that you don't want us to use your information, you must tell the researcher within one month of the initial agreement.

G. PARTICIPANT'S DECLARATION

I have read and understood this form. I have had the chance to ask questions and any questions have been answered. I agree to participate in this research under the conditions described.

NAME (please print)_____

SIGNATURE_____

DATE _____

If you have questions about the scientific or scholarly aspects of this research, please contact the researcher. Their contact information is on page 1. You may also contact their faculty supervisor. If you have concerns about ethical issues in this research, please contact the Manager, Research Ethics, Concordia University, 514.848.2424 ex. 7481 or oor.ethics@concordia.ca.

Appendix B

Transcripts of the first interviews (2016-17 participants)

1.How do you feel about the course right now?	Student G	I think it is very interesting, I have found it giving me different perspectives on science. I have never would explore it otherwise.
	Student H	I like it, I like the people in it. There is a lot of work in sense of assignments and the readings, like in that sense it's probably my heaviest course. Andre the teacher, he is also rally approachable and if you need to extend the deadline or something, he seems that kind of person who would easily allow to that happen. Like if you are not completely screwed or something and just going on in your life and you can't complete something immediately which is nice.
	Student J	I think It is very interesting. It is very different from all the courses that I have taken or all the, I guess, regular courses in psychology. Most courses you walk in, professor lectures and then you get just like midterms and finals. Sometimes you get papers or little assignments to do but you never really have like class discussions or debates and presentations to do. So, it is different. I like the format because it is not just like you learn everything by heart and it is not like just take and exam and all you know is for an hour and that's it. I think the knowledge that we learn or the skills that we learn. I think will be able to be applied in different things later in our life or an career whatever we decide to do, I think it is very broad but very useful.
	Student JS	I like it a lot. Before I was kind of a little bit scared of the course because I was new to the science college and, I didn't know how it works and, I didn't know how demanding the course would be but now that's been a semester. I know what he is asking for. I'd found it very interesting like it's not a normal course. So, it's interesting.
	Student F	I find it different from the other courses. It gives different feelings so, the way we learn is not the same as other courses. I find it more interactive. It makes you reflect over and you're like: Oh, I've never thought about it that way. So, it's more interesting.

	Student I	It's fun class. I like it I mean...I guess I kind of thrive in there except like cracking jokes but it's like a small classroom and allows people to be closer. it's kind of nice. reminds me definitely of CGAP and maybe even high school in a sense because it's a smaller classroom not like course content but just because people are closer.

2. What do you think about the concept of knowledge?	Student G	I think of knowledge as something you can acquire. Something that you are able to get like wisdom is something that you take time to develop where knowledge is what you can learn through text books and through lectures.
	Student H	Learning as much as I can, basically just collecting human understanding, striving to know more. It is kind of abstract but yeah!
	Student J	I think like information, things that are I guess facts and things have founded based on research, based on something more than just a personal belief, something that is applied in the very different aspect of life, different fields, something that diverse.
	Student JS	I don't really know. It's what you gain from experiences and, it's learning. Also, you gain it a lot from going to places and everything but it's also things that you have to learn like for example like going to class. So, you learn something not by experience, you actually learn it and studying it and that's also knowledge.
	Student F	It's not easy for you to find. I guess it's just like how much you can say about something. So, the more knowledge you have about something the more detail you can say to somebody about it and the more you have it the more you understand it.
	Student I	knowledge is the information that you know I mean it's what you can learn it's not like… like someone is knowledgeable knows a lot of things but they're not necessarily smart, you what I mean?! Knowledge is like having information.

2. How do you gain knowledge?	Student G	From other people saying to you and through textbooks is the most working for you to get knowledge.
	Student H	Let's say through having others just verbally sort of speak it to you, through reading it, through just observing it. So, just observing human interaction if you want to learn about how people are and through do research on our own. Like, perform an experiment like manipulating variables. That kinda thing.
	Student J	Well, of course going to school but also I think from talking with friends, talking with supervisors when you do research project or when you volunteer in a lab, reading books… Books are very useful often if we don't get to use text side books because we get textbooks from all our classes and you know we don't have time to go and try to find resources of information but when you do have time it is nice to go out and get good books to read like for getting knowledge.
	Student JS	University, class, everything… but also there are a lot of knowledge that I gain from out of university like through radio or watching TV and also through reading a lot of books.
	Student F	I think through experiences like if you want to know how to read, you have to read a lot of books. If you want to learn science you have to take a lot of science courses and do a lot of problems. So, the more you practice, the more you acquire knowledge.
	Student I	I mean try to ask questions but like especially in that class I mean everybody's close like nobody feels like judged. Everyone feels comfortable. So, I think it's easier when you're in a smaller classroom when everybody knows each other to like ask question and like maybe like that inquire about certain things to get that knowledge everybody is also like more willing to help each other out oppose to huge university classroom.
3. What do you most rely on for getting knowledge? For example, Do you rely on your reasoning or what the teacher says	Student G	For this course, I am finding it… it is very interesting to read the textbook I mean the course pack and listen to class and debate through group discussion but I also find it useful when I am writing reflection papers to make links to what I already know specially writing paper for last semester. I have found it very helpful to go back looking what I am doing in other classes and kind of tie in what I learnt from that and things I already know from high school and CGAPs.
	Student H	I find it tends to be gullible. So, if someone tells me something, I'll immediately believe it which does help as a student sometimes but at some time, I tend to come across a right answer on my own eventually and if someone told me the wrong thing beforehand. Because they want to give it to the teacher and they want to know who target to understand something, it could be rather problematic as a kind of sort through the right answers.

or anything else?		

3. What do you most rely on for getting knowledge? For example, do you rely on your reasoning or what the teacher says or anything else?	Student J	I think it is a combination. Usually when I go to a class if I don't know the material for that class and let's say I didn't take a class related to the class I am taking right now or got knowledge from past experiences that I encountered in my life then for me the professor and the textbook will be the main source of knowledge. obviously I don't take it as this is the only thing and that is how it is and that's it, I think like different professors have different ways of teaching and different ways of thinking as well, so I try to talk with my friends also and see like if there is something that I am unsure of or that I don't necessarily agree with the professor, I might talk with them and might go to see professor and ask if there is maybe another way of seeing things. Also, I do rely on what professor's teacher because they are there and they have done some works and research and they know for sure all more about the subject than I do.
	Student JS	For me, I think what works better to gain knowledge is going to class and listening somebody that teaches me a subject cause I am able to understand I better than if just reading it by myself. No matter what happen even the professor reads the slides, I go to class. For my experience, it is impossible for me to learn myself and I cannot teach myself something. I need somebody to explain it to me.
	Student F	I feel for science you rely on your teachers and your books because it's like foundations and, they already did the research and that's there. So, you need that to build off. So, you rely on what they present to you. So, you need an initial base. It's like not everybody discovers gravity. So, someone has to tell you what gravity is and from there you can figure out the stuff. So, for science teacher can tell you the basic and you can just learn off from there.

	Student I	To me It's a combination of the three depending on certain classes that you can learn from the book and not go to class. some classes it's solely the teacher. some classes it's I mean… obviously it comes back to you like you have to be resourceful and you have to be able pick and choose but i feel the best one is definitely the knowledge from the teacher because it's a lot more efficient and learning like if you go to class and take down what the teacher says and study with that as opposed to like going through like a huge textbook and trying to figure out like what he wants exactly. so, I prefer the knowledge from the teacher.
4. Do you think scientific knowledge can change?	Student G	Yes, it can with Kuhn and his paradigm shift (she laughs). They can definitely change. I mean like Dalton had an idea what an atom was and h built out of it. We just have a lot of models, right? And these models are not necessarily true in every aspect. We can have new models that are more accurate.
	Student H	Yes, for example, we used to go with Newtonian physics but nowadays we know the theory of relativity caused at certain points Newtonian physics stopped working and my friend who is really into physics has said once, you reach a certain temperature the laws of physics seem to break down. So, again I feel like that might have more with all laws of physics not being complete. So, yes. I think it could be changed.

4. Do you think scientific knowledge can change?	Student J	Yes, absolutely I was thinking about it this morning because I had a perception class and the professor was saying that like perception in psychology is one of the field that what they have learnt like 2000 years ago still apply today but in many psychological fields like a bunch of theories that people thought that's how it worked maybe fifty years ago, are completely different right now. So, I think especially in psychology but in other fields as well, like physic has changed a lot. theories re brought up and then it was like: no! and like rejected. So, I do believe that things that we learn right now might not be accurate or might change in the future.

	Student JS	I do think science can change. Because as we've seen in class. There is a lot of concepts and a lot of things that changed throughout the years. For example, when we did Galileo game, they believed that the earth was completely flat and, today we know no, it's not. So, our science and our conception of different aspects of our world and how variables work with it changed a lot. Also, depending on the culture we are in and what religion we have and other social factors. So, maybe what we believe here in north America is very different from I don't know… like Asians maybe think different in that culture. So, how we approach stuff is going to be also different.
	Student F	Not really, I think the fundamental science would be the same, no matter who you are. Maybe you can explain it differently but if you compare what you really want to explain… like gravity is gravity. You can explain it differently but you can change it.
	Student I	Yeah, I mean it's quite possible like I'm open-minded to like to realize that. like people have learnt things in university in the past that they realize they're wrong and obviously, they move forward because like life isn't perfect you know that like we are trying to get closer and closer to the truth but at the end of the day like it's okay, it's possible to step back and realize it's not entirely right this was wrong and then maybe like relearn it and do something different.

5. Were your expectations from this course fellfield?	Student G	Honestly, I didn't know what to expect when I sign up for it but it is already fellfield my expectations. Because expectations that I have are to be better understand what exactly I am studying. Because before I couldn't define what science was but now I have a more working definition for the term.
	Student H	Well, before for me learning about the science involved just opening up a power point and reading sort of basic facts. Where is now I am thinking, science is more something that like I have to research specific facts if I want to get the answer. I have a more practical view of what learning science is rather than sort of students' theoretical view.
	Student J	Yes, I didn't really know what to expect from the course initially. I knew that all the other students who had taken this course really like it and really enjoyed it and they said it was probably their favorite course out of their entire degree. Yes! I think it is very different and I like the fact that what we learn now can be applied later in many different aspects of our lives.
	Student Js	As I said I really didn't know what to expect, I didn't know how it worked. I didn't know about the science college. So, I had no idea what was going to happen but I am happy to be part of it now.
	Student F	I didn't really know what was the course before but, I find it now that the course is fine and from what I have learned, the course seems satisfying. I didn't really have clear expectations to what the course was. so, in that sense I can't tell you but, based on what I've been doing I feel like I'm satisfied with what I'm learning.

	Student I	I mean there's a lot of writing involved and I like to think myself as a good writer. so, that definitely helps get like opinions and points across especially in classroom a lot of reactions and critiques. so, if someone who is not good as... maybe if English is not their first language, it might not be easy but I think that's why I was well-prepared.
6. How do you think science works?	Student G	When you find something that does not fit the current model and really does not fit then you have to find new model to work for it. So, when you realize something doesn't work.
	Student H	I don't know, apart from eliminating the human aspect of science, not really.
	Student J	I think we like to think that everything is very empirical and systematic and you do the experiment and you see the results and then you have like a fact or like good knowledge, I think sometimes it can differ from that track, I think mainly like research, systematic things though, there are other influences like the pressure of funny agencies. So, basically you do research and you can analyze them and that's it but I don't think it is that clear.
	Student F	I feel like science would be always the same. I don't see it in a different context or different rules.
	Student I	I guess it has to do with the fact that there's like some weird anomaly and then makes us to reconsider like maybe some of the basics and some of the laws. we go back and maybe we have new technology that allows us to be may be more
		precise and makes us realize that maybe: okay! actually it's not right and then people can go back to the drawing board and figure out what's really happening.
7. Did you find that Galileo game was useful to understand how science works?	Student G	Yes, it did. Because I have found really showed how you can change the scientific condenses. How you can… how difficult to convince people. I find it, it is important to have sides because you are able to see all point of views. I was a moderate so I was trying to understand a little. It was interesting to see the different perspectives, to understand where everyone was coming from, like conservatives really didn't want to change and were stocked to their certain model where the others really wanted to see movement towards Galileo ideas. It was a good way of doing it. I liked it. So, I think that in society science can cause a lot of controversies. Different people have different opinions on science and the result of science can be interpretive in different ways and because of this people have different ideas and to reach a conscience. We had judges to determine the outcome of that.

	Student H	Yes, it is very important to have different views presented. because or else we get the impression that all of those debates are really just like one sided monologs instead of like actual debates that people have to go through in order to get what we are right now. Because we don't present the fact that there are two sides in every argument then we actually going to science and we won't be prepared for it because we are not really prepared to debate our arguments.

7. Did you find that Galileo game was useful to understand how science works?	Student J	Yes, obviously because even in the readings when you are reading something, this is how I feel, I feel like when something made it to a book or something that had published, it has some kind of credibility. It is easy to read something and be like: okay! That's right but then if you don't think about it further, you might not see the other side and when both sides are presented then you come to see that there is not only one way and maybe there are things that are not mentioned in one of the readings or admitted on purpose or not on purpose but that changes the entire story or the way we see it. So, I think yes! It is necessary to see both sides and it is useful because then we get the global picture and not just one opinion.
	Student JS	Yes, definitely. Being able to see different point of views made it interesting. To see different opinions and to see different aspect of it and also for us to put ourselves into that mindset. even though we know the right answer for the Galileo game we know the answer but it is hard and that's what make it interesting to prove something that we know today. So, I think yes, it is interesting to have different opinions.
	Student F	Yes, I feel like knowing different views give you a better understanding cause if you just look at one view, you don't learn anything or if we did it in one view and that's a view that most of the class had, no one would learn anything. For example, if you see the other views you might not change your view but you can just appreciate more about the points others hold. Also, you can learn about the views that you didn't know.

	Student I	Yeah, it's crazy like the church even less. The church was so against moving forward and being open-minded to anything that like maybe like did not perfectly aligned with their views and so they condemn people for like trying to advance and try to push knowledge and like I'm definitely like more open for like listening to people even if I know they are wrong but like I got to give people shot but back then things were different. it's like that there's always like a hot topic of the day like right now is genetics with all decrease person deathly. so, society could influence what I want to study but I don't think it would change the end results if I were to do the same thing but not pressure by sided do so like if I really maybe do research in genomics or something and maybe I would be influenced to actually start doing that kind of work but I don't think at the end of the day society would influence me. I think the results would speak for themselves at the end of the day and they would be the same.
8. About reflective writing assignments, why do you think your professor has given you this kind of assignments?	Student G	I know for me it helps me to put together all my ideas and not just skim the text, just really pull out most important bits and understand the main concept of it and I find it very helped right before class, I usually write the night before. So, it freshens my mind for the class discussions. I am able to actively participate. it is usually when I am reading the text, like the last reading we did was 35 pages long and during the text I was like oh my goodness, it is 35 pages long, it is really long but when I was writing reflection paper I was able to think. You know it was actually interesting and I am glade that I rea that. So, it makes me reflect.
	Student H	I think to make sure that we actually do the readings and we understand like from where he is going through this discussion and also, we can all actually discuss together. For example, he split us into the groups to discuss what questions are and what our answers vary to our questions. If we had not all done the readings and like we are all not completely up to date, then we can't do anything and we end up being like the third wheel in the group. This will seriously improve our ability to learn. I am just trying to like to think about how and might see it and when I write it has been the way he can understand it well, that's about it. I go too in depth typically.

8. About reflective writing assignments, why do you think your professor has given you	Student J	I think just so that makes us think of it further than just taking 1 hour 2 hour whatever to do the reading and then not thinking about it again. I think thinking about it further like enough to write 2 pages about it is necessary for first, for us to remember this for more than just a week or like the course and to get a greater thought and maybe go beyond what is written there and bring your own ideas. I try like… I make sure that I understand the reading and then I try to think of maybe situations where I talked about something similar in the class or with a professor or with friends or situations in different fields that relate to the reading and then I try to expand on that.

this kind of assignments?	Student JS	To make us think twice about the reading like not just reading it and be like ok that was what he means but reading it and the fact that he asks us to end with a question and it really makes us to think about the actual word and the actual problem of the reading and like how we can go deeper into the reading. I think he wants us to really understand it and ask ourselves questions. Like for example when I have to write question, sometimes I think about like from what I know and from what I just read what question can I ask and how can I relate both things together. So, for example the last week what we did was about multiple personality disorder and if it was a real disease or not and I taught about the classes I was taking for example psychopathology and then I try to find a question.
	Student F	To make us not just read it and make us think about it. So, I feel like you can just read it and understand it but the special part is, we have to relate it to something. So, you have to rethink on what is the text about. So, you can find like an event or something to relate it to. So, doing that you engage more with the text and understand it better. Sometimes you understand everything but sometimes you don't understand one concept in the text and you can have something to discuss in our class. I start reading the text. If I wouldn't know the context or some words so I take notes side by side then I just look at my notes and I try to figure it out that what is the main goal and then I try to summarize that and then once I figure it out, I go back to the text and I try to find something to relate it to. So, I try to develop the point that I was better understood and popped out to me. So, I try to focus on that particular point and then I do the reflective paper.
	Student I	Well, it is a philosophy class and I guess that's what it is but I think that philosophy aim towards less learning about science and trying to open our minds to like the different paths we can take in science and different opinions and realize the factors that may influence us whether we know it or not and all kind of stuff. Again, come back to society, it'll influence us to go one way or another. Did you find it useful? Learning is interesting. again, readings are sometimes being really long and really complicated and sometimes I kind of bullshit some of that the essays a bit but it's nice. I mean I do learn in kind of my own way. so, your kind of get a little guide. I think what he's trying to inform us is that you have some opinions on your own and that affects the way you are learning. I think it is effective I mean at least for me I don't know about everybody else but I guess you'll find out. I mean I somewhat like it I mean that sometimes the reading is getting a little like really deep and philosophical and i was sometimes like what is happening like what is this guy talking about but I mean as more you get to read it gets interesting and like shows you new ideas which is fun for the reading at least and once you get to reflect on it, I like writing. so, I kind of enjoy it. it could change my views ofregular science as I was talking about it before.

9. Are your ideas about learning about science	Student G	Certainly, developed since the beginning and it is developing like last semester was more focusing on physics and philosophy. So, it is giving me different perspectives on science coming from different disciplines. So, it is changing. It is becoming fuller I guess.

different now?	Student H	Well, before for me learning about the science involved just opening up a power point and reading sort of basic facts. Where is now I am thinking, science is more something that like I have to research specific facts if I want to get the answer. I have a more practical view of what learning science is rather than sort of students' theoretical view.
	Student J	I think they are more open in a sense that like I'm more aware that there isn't only one way to do it like they are many different tracks that you can… that can lead you to learn about science or doing a research and yes! I think just the diversity like before maybe not just with this class but I guess before going into university I thought like all researcher do the same thing as they are going to the lab and I had a stereotypical idea of research and yes! Now I have a better idea or understanding that there are many ways like you can do research.
	Student JS	I don't know about learning science but definitely me vies of science is changed. Like at first, I thought science was just that but now I have a broad and complete view of science. Like when we did Kuhn and like the paradigms and everything I was able to see that it is constantly expanding and shifting and changing there are so many other things that impacts on science such as society and like how we approach a subject and how we approach a concept like now my view of science is in a weird way more messed up than it was before. Because I am realizing it is huge. Science is huge and it is not just biology, chemistry, psychology or math. it is everything in between. How we approach it, how we ask questions and how we deal with it and everything.
	Student F	Yes, science before I just thought of it like going to school but, now I have a different perspective. It is not as simple as you think. Now I think differently. You think that you just do science but actually here are many factors, so there is a lot of stuff that I didn't know before. So, I wouldn't say it changes necessarily but it gave me a better picture.
	Student I	Yeah, I mean I think I was definitely subconsciously kind of knew some of the stuff he's talking about but now that I like really thought about it and stuff like I definitely do think about it differently like I'm definitely more open to like going back and like changing like if something is wrong and science definitely more open to like different ideas and really reconsider like what happened before in the past.
10. The reflective	Student G	Considering I have so many introductory courses I cannot be very critical but I guess it helped me to be more critical of my surrounding.

writing and re-enacting to the Past deal with particular concept what about other Concepts have you tried to look at other	Student H	Yes, I have learned to question what my teachers say a lot more cause I used to just accept it like now it doesn't sound right all the time which does definitely help. Like back to school whatever my teachers said had to be right. Now, it is like I have my opinion on it.
	Student J	Well, since I've started the course when I do readings in other courses I try to, I guess, being more not as like naïve and not just take it as this is it and there is no other way. I try to think that maybe there are other opinions about the same subjects or other views and all the information might not be in that one textbook. So, yes! I try to maybe read about it a bit more and concentrate on it and learn it by heart but actually think about it a bit more.
concerts in different ways?		
10. The reflective writing and re-enacting to the Past deal with particular concept what about other Concepts have you tried to look at other concerts in different ways?	Student JS	I think I am able to read better. not reading in the sense of… like I knew how to read before but reading like now I am able to understand it better. so, I think my reading is improved.
	Student F	Not really, the teaching method in other courses is so different in the way that they are structured. Sometimes, it doesn't allow you to have that flexibility to be like 'oh let me look at it in this way or that way.
	Student I	Yeah, there are definitely a lot of stuff that I have learned in that class and I Kind of start realizing in other science classes. Just like how things perceived and how things may have actually gone.
11. What was the biggest difficulty or challenge for you in this course? How did you try to cope with this challenge?	Student G	Well the reading was long and writing was long but it wasn't anything extremely crazy. I have found Galileo Game… it was interesting to have to be critical of what other people were saying. Yes, I find this course like you have to be very critical and I was not used to doing that, I used to be accepting. I was like oh ok I'll take that, I'll take that opinion and I integrated in to what I am thinking but here, you have to try to argue your points. It was something I really didn't work with. Well, I prepared in advance, I realized taking notes very helped.
	Student H	I don't really know. Maybe just talking with people. I don't typically study this course but I tend to work over concepts more. So, I'd say this course is more of a practical one. About science, I am in biology which is mainly just memorization but this more applies kind of style of teaching. It's quite different.

	Student J	I think the fact that they are a lot of oral presentations, I don't really like to go in front of the class and presenting because it is something that's not very comfortable for me to do, I guess it is the most challenging part for me in this course. I try to prepare in advance. As much as possible and make sure that what was to present. I had control over and I know well the material that I want to talk about.
	Student JS	I really hate writing essays and since we are writing one every week that's kind of a challenge but I feel I am better now. The challenge that I am still facing and I think I face it the entire like my entire life is public speaking. I don't know if you notice but I never speak in that class. I never speak because I don't want to speak in public. For writing I just got myself in the right mindset and just was like I have to do it. I don't have any other chance and I have to do it. Now I feel like it is also good and public speaking, I still don't know what to do.

11. What was the biggest difficulty or challenge for you in this course? How did you try to cope with this challenge?	Student F	I'm not used to writing a lot of papers all the time so, that was probably something that I had to get adopted too. For readings something and then writing a paper and making sure you actually connected things. For example, for reflection papers, you need to make a connection to your past understandings. So, it was the hardest aspect.
	Student I	I'm not a fan of speaking in front of people like I don't mind like debating for the whole class but I don't like speeches like I don't like having a prepared speech and going in front of people but like I'll raise my hand and I'll talk to whole class but i don't like having a prepared speech. It again kind of gets better when you start to get to know people and you get more comfortable. Then it's a lot less pressure. Especially getting to know doctor Leblanc like he is a nice guy that also calms me down at least.
12. Were you well prepared for this course before taking it? Do you have a background	Student G	I think so, it is really demanding on the writing aspects and I had very good English teachers. So, I am set for that and in terms of the course context I find the philosophy is very heavy in this course and I really never exposed it this much. I had good humanity teachers at CGAPs. So, it is ok.
	Student H	Yes, I had some pretty good teachers before. Like in CGAPs. They tried hard to make us think about different concepts and all that. So, I had to say yes.

in History and Philosophy of Science?	Student J	Yes and no, I think I very well prepared in this sense that I don't make trouble with the course I learned do well in the class But I don't think based on the other classes that I have taken in my degree that these prepare me for the course I am taking like in most of our classes we don't have to write essays, we don't have to do presentation as well saying so, the things that we have to do in this course is quite new like I have done Maybe in CGAP or high school of course it is not the first time but in University it is unique. Before I did philosophy of science in the CGAP. So, I have a bit backgrounds in philosophy. I did take history of chemistry last semester, not like history of science necessarily, a bit of history of chemistry alone.
	Student JS	No, I have not experienced a course like this before. because we don't have exams. It's only writing and its discussions while in biology and chemistry psychology, a
		course is with a teacher lectures and, you have to learn your lesson. So, it is not th same.
	Student F	In terms of having knowledge background, not in that sense but, in sense of knowing science in general, in having that aspect yes but, to be honest, I didn't know what to expect so…
	Student I	I mean I don't know what to expect but I think I was adequately prepared to do this. I mean there's a lot of writing involved and I like to think myself as a good writer. so, that definitely helps get like opinions and points across especially in classroom a lot of reactions and critiques. so, if someone who is not good as... maybe if English is not their first language, it might not be easy but I think that's why I was well-prepared. I mean I'm so used to doing science all the time and it's very much like learn and apply you know like maybe like put stuff together to get fault problem but this is nice change of pace to be able to express myself and because there's a lot of like opinion base things and there are a lot of reactions and it's nice to be able to like just to express myself on papers in academic way. It's a nice change of pace definitely.

Transcripts of the second interviews (2016-17 participants)

1. What is your picture	Student G	Well, I see it as Much More socially implicated field before I saw it as an objective mathematical field now I realized it got a lot of influence in more social aspects like history philosophy political and religion as well.

of science now?	Student H	At this point a hugely multidisciplinary kind of combination of knowledge like a this point is just a lot of information about a lot of different fields that while bein related to each other kind of aren't like yes new neuro and physics are both relate to each other but at the same time as I wouldn't picture studying both and
		working in both so science is basically just a huge like amalgamation of knowledge.
	Student J	So, again it is kind of very structured way of investigating phenomenon in the nature. I think I said the last time that we see it as a very idealized like authority of how to find truth and Define things very precisely but often it doesn't...it's not as empirical as we think it is and a lot of underlying things like social factors and everything that comes into like the politics of a science that also has impact on outcomes but yes it's this I think the more like I was going to say scientific way but more empirical way of doing research.
	Student JS	I remember this question (she laughs) I think it's still very Broad and it's still its for me my first definition of science was more narrow and today I think that it's like from the course I was like seeing the Sciences way more than what we actually think and that science is everywhere like it's applicable and any other discipline other than science and that it encompasses a lot of like our problems today and it's
		yeah it's very Broad and very general and then yeah it's not just limited to biolog y chemistry and everything it's also particular way of thinking and everything…
	Student F	Science is a general field of study let's say that in what we try to answer questions. could be about nature, could be about biology or anything in general and like it includes those domains and it's more about investigation I guess and like coming up with like hypotheses I guess and like solving and answering questions.
	Student I	It is not just science, it is a lot of stuff around it too. You got that …not just the actual science means labs where you're actually doing some research. You know all the extra stuff that people don't really talk about it all that much. more the issues, more the implications and certain things. It is all that things around it that involves in science and there is always going to be. So, I guess that's for anykind of job or any kind of field.
2. Do you think studying history and	Student G	I think so that it has changed because I realized now that the results of science a lot more influenced by the circle contacts so for example like what kind of political forces are there at the time or like what is the accepted philosophy of the mindset of the people in that period that kind of drives what kind of science is done and what kind of results are accepted While others are more pushed aside.

philosophy of science changed your idea about science?	Student H	Yes, because it kind of made me realize that my teachers aren't always right that this stuff are being taught is still just a theory and while yes it's highly supported most of the time that doesn't mean it's necessarily Flawless like at this point I feel like I can disagree with my teachers like I have that right to where is back CGAP and High School like they were right they knew everything that was basically just the philosophy that we had so yeah.

2. Do you think studying history and philosophy of science changed your idea about science?	Student J	Yes, as I was saying like before doing this class I thought the science was clear and it was direct and there is no bias in any way and you would get to the truth and that's the only thing that would come out of scientific research but all the readings that we done and discussions and debates that we had kind of open my eyes to see that it wasn't as clear-cut as I thought that there are a lot of other things that come into science.
	Student JS	Like I said for the first question I think it definitely made me realize that science wasn't only a certain discipline and it wasn't just like science is math is that...no! Science is like a way bigger domain than what I thought it was and also especially for this semester when we were reading about ethics and like more psychological aspect of Science and how I don't know maybe you going to see that in my reflection papers but my mom is actually a she is a teacher of economics and so I always had that like economics background when I was living with my parents so I feel like a lot of science especially link to psychology you can like relate to economics like i think like science is a bigger domain now and that's what change I think.
	Student F	Yes, because by knowing the history and like philosophy of science it gives you a different perspective and you know back then the reason why they did this was this and it kind of can help you in your future studies like the philosophical aspects you know although you think science is perfect but you can understand their flaws even though they're not a voyage. It gives you like a better picture of science in
		general like it's not just like: okay! Here is the question and I solved it and this is the answer I want. It's more like … you have to take into account all those little things and also like from the history perspectives you can see the other influences.
	Student I	Yeah, definitely. It definitely changed my opinion about science especially in terms of like historically I used to think of people because it's really stupid back then like 1670!!! what are you thinking but when you put yourself in their shoes and you really understand where everything comes from and I really appreciate it like where things are now and the luxury that we have now and like this freedom.

3. How did the course help you to change your views of science?	Student G	Well, there was reenactment of historical context that really were pivotal in science overtime like the Galileo game or the Darwin one it really kind of showed these things that we take for granted in science how back in the day they weren't as obvious and even though there was data to the defendant social forces were slowing it down or really influencing whether this was going to be accepted or not so I found it really good to take on that role myself since I was on the side that was against Galileo in first semester so I really had to be in the role of the character that didn't accept this kind of viewpoint because it had a social implications that would bad for me so I understood why someone would be reluctant to accept certain views.
	Student H	The constant debates definitely helped because it kind of like open my eyes to the fact that there's more than one more reality like there's more than one viewpoint on every subject matter regardless of whether I agree with it the fact means that it exists. so like for good While, religion really was considered like a good alternative to science and then he was kind of modified to be like a partner of Science and this point it's more seeming to be something that kind of inhibit science just the fact that we saw these different viewpoints and we debated about them kind of helped.

4. Do you think it is important for University science students to learn about philosophy and history of science?	Student G	I think so because then especially for me I realize that a lot of the theories are like especially like with this semester we were doing a lot of psychological issues a lot of our theories are based historically and on the mindset in a lot of the philosophy of Sciences and sprinkled in our books you don't like we kind of get taught this philosophy without realizing it and when we can actually see that this kind of mindset we were brought up with and it kind of influences the way we interpret our result, the way we see science and if we can tell that there are problems potentially in the way we interpret we can kind of maybe strive for something more objective and I find even in my statistics class we were talking about how the way we interpret results are very arbitrary that the P value is .05 based on a tradition we just choose 5% like that and even the P value itself is somethi was in science college because he was saying that I was wondering if this problem of interpretation excepting of results was another fields that really show that even in other departments something like mathematics statistics can have problems in
		terms of interpretation and I think it's important so that we can maybe try to mak this happen less often.

	Student H	I would say yes but more for the class itself than necessarily the material presented in the sense that ... the material that presented could have been quite different and still have achieved a very similar result because in my opinion the most useful thing were the debates and general information about like paradigms and all that. like as long as we have the debates that prove that there are different viewpoints and we understand the general idea that what we all currently believe isn't necessarily the truth and 100 years we won't necessarily believe the same thing. so, as a scientist like you always need to keep an open mind. So, knowing all that were good. it's like yes or no this class is incredibly useful because the material could be changed completely but still have like the core element that is incredibly useful so yeah.
	Student J	I think so because philosophy is at the bassist of many scientific fields and it just pushes any students and people in general to go deeper in their reflections and not just take everything at the base value because I think the biggest thing that I take from this class is that there are more views and more things that are often presented and so if you don't go Beyond and try to find opposite views or find other articles that talk about it in a different way, especially these people are writing this... they have their own biases so it's never just like this fact alone like there's always influence of other things like social factors such as religion in Galileo case, and so if you only take one opinion out of however many there out there it really affect the direction that you take towards specific subject.
	Student JS	I just like culture like general culture like now I know way more about scientist and way more about different aspects of science that I did before. I know more about dates and like names and everything. I wouldn't say that it's… like it is very important because it's culture and culture is what you're going to gain and what you are going to keep it forever. So, yeah, I would say that it's very important to understand since we are all in science and we always learn about theories and like how I don't know math and everything so it's interesting to learn about more of the not the theory part but more like the how it got here how it got there and like the history of the science behind all the theories so yeah it's interesting.

4. Do you think it is important for University science students to learn about philosophy	Student F	I wouldn't say it's necessarily important but I feel like it's very enriching and it helps you understand more because like by knowing the history and like the philosophical aspect when you do like…. When you end up doing research or whatever, you can have that like the edge of your critical thinking, I guess, but like if you're just here to like study Sciences like straightforward it's not necessarily and acid I guess but it's something that really worth. like it's the class that like... it helps you rather than like that determines because like you got the...have a broader understanding of what you are doing.
	Student	It's definitely cool but there's just so much of it that like you know like yeah it ha to be like an individual course is cool for sure for something like this to trying to

and history of science?	I	understand world or how far we've come, it's more of a history class and I guess a philosophy class too right. I do think it's important for people to really understand where things come from in terms of like…you kind of develop some empathy more with it because you kind of try to put yourself in the shoes of people from the past and people that you disagree with you can kind of take a step back and be like: okay! like what's really happening here I mean it's cool as a science course but I mean if you were as part of other classes it is kind of difficult because it is a lot happening you know if you're going to learn it as part of the biology course but there is also a history portion too. So, I think its cool.

5. Do you believe that scientific knowledge can change?	Student G	I think so because like we saw scientific knowledge is just what's accepted right now what the data shows but there's always errors and interpretation or not necessarily errors but limitations in interpretations where we don't have enough knowledge to be able to make a full interpretation of what we have known and so I don't think it'll be dramatic changes in knowledge as time goes on because there's more and more so it's harder to make large faulty interpretations but I think it can be changed if we find errors.
	Student J	I can kind of see it happening. the things like we do change paradigms a lot (interrupt) We often change paradigms and when we do often times the information that we used to see it like solid and flawless is kind of just cast aside because we realize it is wrong kind of like how we used to believe that Aristotle's model of the universe was solid was the way everything worked but now we realize it's basically just a fairy-tale so in that case like scientific knowledge has changed we completely threw aside all of those theories and came up with like new or better ones and we saw sort of changing paradigms again and while we won't completely throw away what we currently know because what we have right now is based on actual observations the fact remains that were still likely going to have a completely different opinion in a couple hundred years.
	Student F	Well yes, as we saw it before.
	Student I	Yes, I think it definitely can change you see that everyday, you know, science is not just like one thing. it's a continuous flow of information. It is not all set in stone. we got our theories but even though sometimes we are subject to change like for a longest time we thought that like Newton's Laws where absolute right but then we found out that it's not, like it counts for like big objects and like big things but doesn't really count for the small objects I think I don't know the details. So, that theory breaks down. Einstein came in and kind of change everything everybody's views first everybody was like you're crazy but then... so, science does change.

6. how do you think scientific theories can change?	Student G	I think it kind of depends on the field because it would be different for example in chemistry I think like different theories like atomic model how it was replaced it's more whenever a new phenomenon shows up that the old model can predictor or explain and there's a lot of evidence for that new phenomenon that becomes important people can't ignore it anymore it's no longer seen as one study that has, you know, potentially like false result on a certain seeing that this is a real one that
		we can't explain anymore, we create a new model that takes that into account. And I think it really is less a throwing out of old information it's more creating a new model that can accommodate for things we never saw before.
	Student H	I think the process is really slow moving and you don't really acknowledge it while it happens but basically you have like this one huge theory that everyone more or less agrees with. then when eventually you realize that they're quite a few flaws to this Theory someone comes up with another theory or maybe a few people come up with a few different theories but eventually we realize kind of fit the whole is a lot better and we put together to form a new paradigm that's slowly replacing with the old one mainly through a process of death because all of the scientist that used to believe in the old Theory and who were like hard into it end up dying or just retiring and all the new scientist that have a new Viewpoint and a new way of looking at things and who aren't already incredibly biased because like their whole life's work hasn't been around this one flawed Theory kind of thing. they sort of take over and they make their Theory take over as well.
	Student J	Well, when they brought up the scientific method, I think it's just there more specific to certain things like that there's less of this Universal explanatory power where it's so vague that it can fit to pretty much anything and so I think other because other scientists are more critical of what they read and what they look at, theories are more specific and more I guess testable verifiable than some of the previous theories.
	Student JS	I think it goes with the question of how a science work, I think that was a question. It's based on our environment and our environment is changing, we are changing like we as human are changing. We have different ways of thinking but it's also based on previous theories and how maybe today would certain qualification and certain way of thinking and different instruments we are able to know more about a particular thing. So, we are able to say if the theory that we thought was true at a time is actually false. So, I think has to do a lot with like technology, us and different ways of thinking in different aspects.

	Student F	I feel like it was explained with Kuhn's paradigm shift but like I wouldn't be able to like …. I don't know… I guess it's like...must be like a really long process and like scientists must like to have their own debates pretty much like in Darwin and Galileo. it has to go through that phase of resistance and like people trying to support it in general and then like even though… yeah like I feel like the change in new theories definitely goes over time and like people don't accept it till like it's been around even though... I don't know how to say... it's like you have to have tribulations kind of like a paradigm shift really. Like there's a crisis and you have those big debates going on. So, it's like a Circle event that happens I feel like it's a pattern but the way it plays out won't necessarily be the same in both like I feel like with Galileo he was in court but it's pretty much the same thing that happened with Darwin with just like scientist debating.

6. how do you think scientific theories can change?	Student I	I mean definitely a lot of ...it's like some of the individuals who work very hard on their theories. some of the Brilliant Minds that really come up with these things but it's also once your new ideas out and then scientists start like reviewing these things they start realizing okay then math checks out everything kind of works and they start realizing that maybe this is true and at first is kind of just like asserting yourself and that's who you know before I like everybody just squash your theory. You really have ...like people really have to like to assert themselves like, I guess, really push for what they believe in. I think that is what a lot of people did. Especially like Galileo in terms of like when he was talking about heliocentric model, I mean, yes heliocentric model and he even went through a house arrest. That's how far he went until like he really pushes his ideas. so, you got these characters that are the driving force as a whole, I think, the whole Community also involved in that.

7. Did you find Galileo and Darwin games helping you to see how science works?	Student G	Well, I found… It was a little difficult especially in the Darwin game because in the Galileo game system wasn't a lot of scientific advancements I mean if it'snot as much it was easier to bring in religion because science that have as much backup and so even the scientific side had to be quite fake in their interpretations and so the science was almost as legitimate as religion back then because a lot of it was based on beliefs or preconceived notions. While the Darwin game there's a lot more I found frustrating I think it's also cause I was on the other side it was frustrating to have to argue against non-evidence, you know, cause then there's nothing that they're really arguing, there's no backup while there is a backup for the other sides that I found it a little difficult to have them combined but I found it was very well like recon ciliated when the people were suggesting that if religion is taken in at essence it's not meant to in any way interfere with science if you can be religious and scientific at the same time as long as you take the essence of what your religion is telling you and you don't take it literally which even in the Galileo game religious people were told or not were told or where the one is saying that you don't interpret the Bible literally. Even religious people agreed that not necessarily Bible but any religion don't take things. literally take them in essence and then make it reconciled I found that very nice for some people are actually religious.
	Student H	Honestly, i found it really funny! because a lot of the time they were like getting insulted for all these crazy and terrible theories that obviously couldn't be right and yet the people saying those things were so wrong. We don't even remember who they are! like list of the human that exist. I kind of just find it funny that while they did have to push a lot and they didn't necessarily get the credit they deserve, we still believe in them now and like we can recognize they are genius. So, it's definitely an interesting view point to have.
	Student JS	it made us think of the way that they thought before and it makes us like... also in a broader way it makes us realize that a lot has changed that a lot of our way of thinking changed things for the butter and then just to make us… I think he does it to make us try to really find arguments that go against what we're supposed to believe in even if it's like against our own beliefs. So, I think it's like a hard work to try to pinpoint the little arguments that could work in a way.

7. Did you find Galileo and Darwin games helping you to see how science works?	Student F	Considering they didn't know the knowledge that we have now you would think for them it was more like of a bewilderment because Darwin and Galileo Theories are very evolutionary and like out of what people were thinking back then so in that sense for scientist, they probably were excited or they were very scared in the sense that… maybe because they didn't want to see the change, you know, we had conservatives and more liberal characters in the game. so, I feel like the liberal one's present those they were like excited for the change the Science when they got new answers and then those were more like on the conservative they're probably like more like: yes! but we shouldn't be like rushing into answers and we have to take out time and try to avoid the change that since I guess.
	Student I	I mean by role playing like not just like... instead of just writing down reasons as to why do things like you actually have to like to make… come up with arguments with the stuff that you have it is like you're more into it, like you kind of want to win so you kind of go more in depth as opposed to just maybe writing an essay being like: okay! These guys thought this and that guy thought this and that was that! But here because you are doing it yourself and you should get to hear the other person's point of view and so they're going very in-depth and you're going very in-depth and your kind of coming together and like talking to each other and I feel like that's the best way to learn like when you teach each other not like you just sit down and like memorizing things. , I guess, for back in the day and now I supposed to kind of makes more sense but people are still bitching about it but yeah I mean I don't see the issue but I guess it is difficult to try and fit religion perfectly into what science is and like what it actually uncovers and some people disagree with it. So, it is tough. like in the southern United States are people that still like deny evolution and of those kinds of things or parts of the world also. where at least science… I mean certain parts of the science…yes... kind of accepted but still some people deny physics or engineering or certain biology things. I feel like some parts of the world that are still like pretty religious are still like some conflicts that exist between the science and religion. I am not religious myself and I do think they can coexist I just don't see it very working. for a long time for religion because they just keep losing grounds of they have like... what is reality, you know, because it is like: oh! well science comes up with this but then religions... okay with religion we can explain that but then
		we have to step back, we have to start liking it. because they're losing ground ove what authority they have over and one day it might just become irrelevant.

8. why do you think some of the scientist are so well known?	Student G	I would think well-known is different from successful because well-known I think a lot of it has to do with kind of like rhetoric. right? like a kind of in some way comes back to that were like some people in our class they aren't necessarily the best arguments there are some a little bit quieter but who have very strong arguments. I respect them until I actually like they're one of the stronger students but there are more students that are a lot more like better at presenting themselves and a lot a more convincing in terms of speaker. it's easier to get, not entertaining, but I would see that as kind of like a parallel of scientists where the ones who have results that are more popular who are presented in more pop culture way that can be interpreted by non-scientists as important then they become popular. And it's also like the way they look as well like Einstein had a certain look that is typical and I think that played a lot into what made him popular outside of the scientific world because nonscientists don't really understand relativity. Even some scientists you know if it's out of your field it's complicated. So, he became popular a lot because I think his maybe not his scientific side but it's a lot socially implicated.
	Student H	The way I See it if they have a good theory and a lot of good connections then odds are they can make their theory is more widely accepted at faster rate so that while they're alive they're recognized like in Galileo case yes, he was recognized but and well-known and he wasn't exactly liked where in Einstein's case, he did have a lot of good connections and was already like completely full...absolutely brilliant it's like he became well-known and liked well-loved simply due to those trades.
	Student J	I think It has to do with the story that they carry with them like Einstein was a very impressive not impressive but interesting persona like he wasn't just the proper and he looked different and he came up with this great theory but I think it's kind of why... it's a popularity thing and I think it has to do with like the views of society at that time and what they want or what they portray as scientific leaders and who they want to see there as well. So, I think it's more of a like image thing than the actual work like of course the ones that we better popular and had done great things but there are also a lot of them that we don't hear and a lot of women that we don't hear about and yeah, I think it's just the ones that we talked about are the one's that easier to talk about and not as controversial and just like fit the typical or stereotypical scientist.
	Student JS	I honestly think a lot of scientists are known like a lot of the clinical psychologist or a lot of the like for example dr. Phil he's super known and he's supposed to be a scientist but like is he really though? like he just… he has a talk show and says like something that anybody could say. It's very publicized and it has to do a lot of with ...in this case it has to do with personality like how he acts but scientist like Marie Curie, she was the only woman to have Nobel prizes and she was amazing so... I think because like Marie Curie and Pastor it's more like...they found a vaccine against rabies. It's more like… not that it's going to help more people but it's mor

		understandable for the entire population then X-rays and how he discovered I don't know who discovered what but like how he discovered that there's a tiny little particle that does that and I think it's you can relate more to finding a vaccine because we all know how it looks like we can all… we've all got vaccines than a tiny little thing that we can't even see we don't know what it does and I think like there are less known because people can't really relate to it and don't really see the application of knowing that this thing exists while with a vaccine you know exactly what's going to do even if you don't have a scientific background I think that's maybe why.
	Student F	I guess, for example, Darwin's theory was more General in terms of it had a lot of applications and like biology in General is a bigger field.so, to that extent people know about him and it's more talked about because not only touched science but also like touched like the religion and bible and people like they like believe Genesis like they obviously might have been one we heard about Darwin or not so I feel like just the nature of his theory makes it more of like a public type of conversation of people have. Like Helmholtz like it's an equation and it is very specific and you use that more for applications of like I don't know to create devices and people might be like touch it in everyday lives but they won't realize it's not necessary and it doesn't have that aspect.
	Student I	I mean some of it…. unfortunately, like there's a lot of people who go unnoticed in history who made hugest discoveries and like say the guy who invented vaccine and like nobody really talks about him that much. I think it's also like they're kind of like Superstars too. Right? said those are ….some people who like you can kind of think of those like actors I guess some of them are really popular some are very eccentric some like really make an impact they just fight and whatever... and some just have a really good idea and some of them have really good theories and so like that those two things are just a combination that like people remember them like Galileo, like sure there are other people who had shared similar views to him but I feel like because he made like such a scene at during that time you know it was such a publicized affair that like he just became well known and then for Newton like his work was like pretty great and so it's kind of hard to like not remember the guy like Newton or Einstein.

9. Through the discussions, when you were in general public group, what criteria had you consider choosing one discussion over the other one?	Student G	So, Irealized different judges had different sort of ways of choosing which group did like better and I like to not choose based on who's saying it like I try my best to kind of separate the people from the arguments and I try to just remember: okay…! how many arguments were they able to make and how strong were they and at the least amount of weak points even if the other group didn't point out any flaws in their arguments if I noticed one I would count that as maybe like a loss of points or credibility for that group. So, I kind of measured how many they had arguments they had that were the least flawed or the least amount that were bad. So, if they able overall to be a stronger argument then I voted for them but I realized it was very easy to vote for a group that had like a good ability of rhetoric you know someone who's presents well who has a more like loud voice and who speaks better. It was very it was more convincing because that's what I realized even in the games people who arguewell and who are good speakers it's easier to vote for them but then when you really stop and think about it but I normally voted
		for them because they were right and then not necessarily better argument. The argument might just be empty it's just they can say it well and then I tried to do that myself in my arguments that's why I noticed it because I tried to make the argument sound nice when there's not good backup if I was in a religious point of view so I found that difficult it since I noticed that I tried to avoid that.
	Student H	Typically, it was well-reasoned and like diverse Arguments for me like that held the most weight. So, if one group just kept on saying the same point even if it was a good point I wasn't really inclined to vote for them simply because like there's no creativity there like it just kind of seems like this 5 minutes thinking and nothing else where is if the other group came up with a lot of points even if they were not necessarily good points like the factremains that they spent a lot of time thinking about it and that kind of just help me to persuade. I will admit that I was kind of biased towards ideas that I believe in. yes, that think most people were but I did try to go with like whoever gave the better ideas and like more ideas.
	Student J	Like of course we, as the either the judges or the people who would ask questions we all had our own opinions on the subject but I think when I was a judge we try to look at the variety of arguments that they addressed this specific question cause often the question itself I found was directed It was easier for one group to answer than the other because if you looked at the very essence of the question you could go on and go back to that question and say: well! because of this, this, this…. it works better than the other side. So, I always thought there was kind of side that was favored based on the question but I think yeah, the diversity of the arguments that the groups would bring up if we saw that a group were tried to just focus on the same argument and try to bring it back and different ways versus a group that would bring new arguments every time that they had to speak we favors those and quality of the arguments of course.

	Student JS	That's the thing that was interesting actuallybecause it's related to the question of beliefs because we would choose a group not based on our own beliefs but based on the power of their arguments. So, even though I didn't believe… I don't know for example one topic was about...what was it about...about like if there was designer, a big intellectual designer for like how we are and like related to the aspect of God and everything and then so that was for and against and it's interesting because we have to choose not based on our own beliefs but really based on how strong our arguments are so even though I didn't agree with them if they had better arguments we had to let them win because that's what matters are the end if they're able to defend their point.
	Student F	when we have to judge them I guess like sometimes it's like just I feel like the way they are calculated the theory but like for some people like I don't know if you were happened to be in psychology like sometimes they brought theories from the field to like construct their arguments like kind of gave their arguments credibility like how…I feel like how well you gather your knowledge into like your one argument to make it seem like ,you know, cuz you are trying to be the other side like how well formulated you use your argument and how far you can grasp your knowledge instead of just reading the text and just taking the arguments that the

		text gave you. so, like that was like one thing that could make a factor and also like I guess how you presented your arguments in general and like the response to the question if it was a safe answer that could be like you know just like: okay! I don't know, because sometimes they can save the safe answer but when taking back roads, in a way, just be like saying neither side is better and that making your side better than the other. so, I feel like those are the two main things I like influence the decision.
	Student I	When we were discussing different articles? **Yes!** we each came up with a question and essays and I say maybe four or five questions to come up some were more basic than the others maybe some people's been spent more time trying to think about questions and some of it was just that... some of the questions that we brought up required more thinking more piecing together of information more deep kind of questions and then some of the other questions, you know, we didn't just want like any simple answers or maybe questions that were open to debate.
10. What did you learn from this activity, why do you think the professor	Student G	Maybe it was to make us able to use our own… like the value judgment to judge arguments ourselves instead of being told what is a good argument or legitimate point of view we had to ourselves measured this group defend itself properly whether it's our point of view or not or their point of view or not. So, we could tell some people when are comfortable defending their point of you because it was the opposite of what they believed it but to see if they could still come up with a good argument despite a position. So, it helps us to be able to judge when

has given you this activity?		

		someone's presenting appoints what is considered a better argument and so it's good for us to have that experience.
	Student H	Probably just to be able to like only analyze different situations cuz like as University student you can not just listen and don't really do anything other than that like you listen to your teacher that's about it where as in this situation we essentially were like the teacher in the sense that we decided who is right and who is wrong instead of someone telling us what is right and what's wrong which honestly probably give us a lot of good like experience and just prepared us for future careers as scientists.
	Student J	Well, again even if you have a very strong opinion at the beginning, having to go and argue for the opposite side can make you really question your initial beliefs and maybe change your mind. so, I think it's important before you take a final decision that you look at both sides. Why do you think the professor has given you this activity? I think Because he wanted us to see that because it's one thing to argue for the opposite side or for the decide that you have that you favor but to see it from an outside people might think of argument that you hadn't thought of and that can bring up other ideas and also I think to make us realize how difficult it is to make a decision once you've seen both sides of the argument because when both sides are arguing and they got good arguments coming both ways it's difficult to say: oh! well this one is clearly a lot better especially when it's a field that's growing and that there's not there's still not a lot of evidence for or there's evidence for both
		theories at the moment. So, yeah, I think to just make us realize how difficult it is to choose once you see both sides equally.

	Student JS	That it's hard to choose (she laughs) ... because I think in this class he really wants...he doesn't want to be a professor. He really wants us to like not that he's a super good professor that he wants us to take more part it's not like a normal class where we just listen to the professor. Here it's more like we are... each student is a little bit of a tiny professor and we each say something that's going to like trick something in somebody else's mind and that person is going to say something. So, I think he wants us to really take a big part of the class. So, that's very interactive and so that it makes us think in ways that we wouldn't really think normally. So, even being in a group for or against intellectual designer if you're against it and you believe that it's actually true but if you have to prove that it's not true and makes you think and makes you find arguments and even if your general public you're able to see opinions that you… that by just being in a group for or against you wouldn't see it like you wouldn't be able to really understand both point of views. So, I think that's why maybe he wants to give us that discussions.
	Student F	I guess it's like when you're debating you have to really…. like when you are looking at one side and trying to see the positives and why should support like the specific question then you have to use your knowledge in the best way as possible and try to understand and more like the more you understand what's going on the better it is for you to understand like why would there is no question on this argument or why this argument is real for example. So, the more you know the better. I guess it's like instead of him telling us: okay! these are the goods and these are the bads by making us debate because Just by debating you have to be competitive. things that you want to work on them in order to actually win and then like that forces of students to come up with basically what he would teach us presented in a different way like you'd be learning but you wouldn't realize it because your main goal is just I want to win the debate but like indirectly you'd be learning.
	Student I	I mean a lot of it I guess is for doctrinal differences and to you know if you could... if you really go in-depth if your team you know ...we find all the points that we think are relevant and we argue them and then the other team comes back and we're forced to like really listen to what they're saying because we want to win the debate and so we're forced to come up with more ideas on our side that can count on our arguments and so I guess you learn more that way about your subjects.

Transcripts of the first interviews (2015-16 participants)

1. What expectations did	Student FR	First, when I read the description of the course, I thought, OK, well I'm going to learn about the different aspects of science. When I'm like researching

you have about this course when it started, two weeks ago?		about something or when I'm like, I don't know, just like see the world from a different perspective. I find it very interesting. I'm expecting to learn a lot.
	Student L	My expectation was a lot of fun, a lot of orals, an entertaining class, and rediscovering some of the old philosophers and mathematicians. Knowing more about the history as well, because I'm really bad at history. And the oral presentations I'm really looking forward to. And it's only essays and I love to write, so.
	Student N	What expectations I have would be to understand more about the trial of Galileo and about his theories and also if you look at how far we've come from science too, with all the theories like Aristotle, which didn't make sense. Some of them were like, but just to think that they didn't have the technology that we do today to realize what's right about the world and what's wrong. I also find it interesting that we are going to do a debate. Because I thought it would be like lectures, you come to class, you write your notes, you do your quiz, but in a way, the debate it's more like...I'm a bit shy, you know, to speak in front of people, but at the same time, it forces you to not only understand the theories but also to memorize them and to remember them. Do you know what I mean? Not just like, OK, I'm going to memorize them for the quiz and then forget them. You actually have to learn and make it ingrained in your mind. I'm expecting for that to go well, hopefully.
	Student P	I didn't have any expectations at all. I only just picked up the book and I was like "what is this?". Obviously, Galileo is very scientific, but I thought it was going to be like a pure, really science-based course. Like science methodologies for research or something. Seeing the book, it's a lot more philosophy about science, and it's about how science had to push its way through preconceived ideas of religion. And I think that's super interesting. It's a part of science that we don't get to see, usually. In Biology, you see the evolution of like microscopes, but we don't see the societal image of science through the ages. I think it's going to be fun, but tough at the same time. I'm not really good at debating. So I hope that maybe I'll integrate certain skills I learned in this class to my life. Learn about religion a bit.

	Student M	I don't know. In some way I take it as, it's really going to be a team-building activity, like getting to know all the first year science college scollies. But also like I guess I have a much better idea now than I did last week, before the first class. So going in, I was like 'OK, we're going to do...' I didn't know. Other than the title of the course. But that's why I was expecting it to be more like, my expectations were really around the relationship building with my classmates. And now my expectations for the course, having done one class an read the texts, I would say it's going to be very interesting. I hope to improve my ability to debate. So I did debate in like Sec 5, in English class. It wasn't super in-depth, so I'm not very great at that. So hopefully I'll improve. That's one thing. Not knowing what faction I'm going to be in, I want to make sure that when I do the reading I'm not focusing just on Galileo: I want to be

		able to argue the other points, so I put a lot of effort into understanding Aristotle and then Galileo, well, I would side with him, personally (laughs). It's like, that I can look it into. But it's just like underlining possible arguments for Aristotle as I went through. Planning ahead. Because I don't want to have to re read this three times (laughs). And, just knowing the class, I feel like the texts were well chosen, they present both sides of the argument very well. So that's interesting to me.
	Student O	About this course? I didn't know it was a debate class. I was talking to one of the guys before the class and he told me it was debate, and I was like 'oh my gosh'. I don't debate. I'm shy. So I guess what I expect to get out of this is to be comfortable talking in front of a crowd, and sharing my ideas out loud. As for the writing, the reflective writing, I've done essays, argumentative essays before, so that should be OK.
	Student Y	I had heard people speaking about it. I knew it would be a different kind of learning experience, but I wasn't sure how the game and everything was going to develop.
2. *now that Dr. Leblanc has presented the reacting to the past role games and the reflection papers, what expectations do you have about*	Student K	I think it's going to be mainly like debate. And, I don't know what to expect really. I don't know what to do for the presentations and papers. I'm like, when the game starts, I'm just going to go with the flow and like catch up with everything, because right now, I'm really really lost (laughs).
	Student L	I want to learn how to write good papers, because I thought my English grammar was good, but it's not. I have issues to work on. So yeah, enhance my writing of scientific essays and my persuasive writing. That's pretty important in life. Practice my speaking English as well.

the structure of the course?	Student N	the fact that we have to write papers and they are due in only a week, and you really have to understand, and the concepts aren't that easy, especially Aristotle. So when you read them, it really takes a lot of time to understand, so you can't just do it last minute.
	Student P	I think it will teach me to have a more of a global perspective about some things rather than really the everyday life utilities of something. Like, this course is so much about the global impact of science and how it's come to be through the ages, and maybe I can apply that to all types of science in my life, and not just focusing on my everyday studies of learning which bone is where in the body. But maybe how they were discovered, or if there are any ethical debates about, I don't know, dissection.
	Student M	Again, for the readings and the papers, it's going to be easier to do the readings in the week and write the paper in the weekend. As to the game itself, I don't really know how the prep is going to go on a week by week basis. But I feel like that's going to be a lot of group meetings with other people in my faction to debate the issues. So that's what I think the work entails in this class.
	Student O	I guess to help me overcome my shyness, it would be to get to know everyone on a personal level, like a big family, to be more comfortable. I've spoken to a few of them, so I hope Monday it will go well. Writing, sharing ideas, helping each other. For sure talk to André, so that he can give me pointers. He's really nice.

3. How you view science in general, how science operates, how you think scientist develop their theories?	Student k	Well, I think it's been the same principles since Galileo. You just observe it first, make your hypotheses, then researching and having some options and checking these options and staying with the best one and keep on researching with more people. Yeah, that's like the methodology, that's it.
	Student L	I hate that kind of question (laughs). I think that science is all about questioning itself and trying to look for answers about everything around us and inside us, and wanting to know more about everything. We have a lot of technology that really help science to progress. We invent new machines and we discover new things using that technology. So I think the advancement is really due to that. If we didn't have the technology, science wouldn't progress. And maybe also the fact that now, we prioritize knowing compared to before. We emphasize knowledge and learning.

	Student N	They...I don't know. *-Just your general idea of how science works.* -It requires a lot of studying, I guess. It's a lot of curiosity. Your mind always has to be thinking of what-ifs and different theories how they can come together. Also, I guess you need to have great knowledge about the past of science, to kind of know the laws, you can't really, you can't just show up and say 'well this might work' out of the blue and then it's like no, this defies the laws of physics or defies the laws of this and that. Does that answer your question? (laughs)
	Student P	In terms of theories...I think scientists go from the things they know and have a question in their mind about something they want to know, and then develop a hypothesis from that. That really resembles one of the questions from the interview to the Science College (laughs).
	Student M	It's very...oh gosh. Constantly, they're telling us it's all about. The thing is at this point, where I am, it's always been book learning and application-wise, in a lab a bit, but even in the lab, the experiment has been given to you, so when you're actually building your own lab, I expect lots of failures in results (laughs). But also, from what I understand, it's not solitary, it's also a lot of labs with lots of people working on the same thing at the sametime, so that'll be interesting when it's a more social environment than reading your textbook at home. But science is the pursuit of knowledge, like the laws of nature...Like trying to understand how the world works and what's going on and 'why does it do that?', even if you're just pursuing this tiny little thing, you're looking at this 'what's happening?'. I have friends who are doing body science morphology on flies

		from the Arctic and...You're just looking at what's happening specifically to this fly in the arctic, in this changing environment, but it represents so many other species that are being impacted.
	Student O	Well, for sure through observation. That's a big part of it. Testing it out. Seeing where that leads you. In science, there's not really a wrong answer, because you don't know, some things are obvious but, let's say in Psychology, there's not really, we never really know why someone is like this or that, so there's no concrete answer. –So the answers that we do choose, why do you think we choose them? Because the majority...how do I explain this? Let's say you're doing research and if the majority of people you're researching with have that outcome, those results, then I guess that can be the answer there. But sometimes you don't know too, and with the environment, there are other factors.

	Student Y	Well it's mainly, from the studies I've read, it's really about not sticking to what you know, but going outside of what you're supposed to know. Looking at other people's work, obviously. You're not going to repeat an experiment if you already know it's wrong. It's very important to learn from other people. As soon as you're trying to stick to what you know as an individual, you can only go so far. So helping each other is big. Making sure that things are replicated properly. Another way to progress in science is to look outside of the scientific fields, you know, looking at social issues or cultural issues, things like that. It's also important in science, because everything in the world is interrelated. Religion and science. Religion and culture. Culture and science. It's all kind of one big circle and we are all part of this earth. I guess, without getting deep. You're supposed to use external factors to complement science.
4. How do you usually go about learning? Like, when you want to learn in a regular course, say, how do you do that? how do you usually approach learning new concepts?	Student K	- Well, I don't take notes during lectures, I just pay attention and try to remember everything. Then, I make some time to study and when I study I make my notes and I study by myself. That's what works for me. - OK, and do you do the same thing when, because I don't know how it work in chemistry, but I know in biology for instance, sometimes it's memorization, and what I'm interested in is really when you're trying to understand a completely new concept. Do you have any strategy for that? - Well, I try to relate it to something else. Because, everything in chemistry is related to something more basic, so I try to relate it to that and then you got to be really smart and like, think all the time, it's not just memorization. So you gotta be a mathematician and remember things and apply everything together, that's what I like about chemistry, it's not just like memorization.
	Student L	It's not really memorizing, it's more like creating stuff and writing stuff based on stuff we know. So I can go online and look for information or in the book, read them, understand them, and then start to write my essay.
	Student N	- If I read a certain theory that I want to understand, I usually always refer to the internet. I go on, a lot, I google a lot of things, but I'm not just going to go on one website. I'm very picky. I'll go for 4 or 5 websites and see what they have in common. Even examples, if I can
		find pictures or diagrams to explain the theory – I'm more visual for that. So it helps too. - *So, did you enjoy the mind map?* - Yeah, that was pretty cool. I use a lot of colouring too, like colours in my notes and I do a lot of diagrams too.
	Student P	I'll give you just an example. For my anatomy course, what helps me is reading and reading and reading. I'll read the book before class, then I'll read my class notes, and maybe I'll make a sheet with the structure, or the information. But I think that for this class, it's not memorization that's going to be needed, so I think it's a lot more making links, researching and understanding.

	Student M	I guess there's different ways I do that, depending on the type of things I'm learning. Like in this course, it's different when you're writing something and understanding concepts, it's different than just straight memorizing for biology, in which case it's just like review and then write and then review again (laughs) In this class, it's more going to be like reading the text and what do I get from this paragraph, like take notes on the side, and then I guess I make an opinion. That helps me to then build an argument for an essay. I'm terrible at building essays! I don't find that I write well, argumentatively at least.
	Student O	I guess to help me overcome my shyness, it would be to get to know everyone on a personal level, like a big family, to be more comfortable. I've spoken to a few of them, so I hope Monday it will go well. Writing, sharing ideas, helping each other. For sure talk to André, so that he can give me pointers. He's really nice.
	Student Y	Besides paying attention in class. When I'm learning neuroscience for example, I find it useful when teachers link brain structures to diseases in the real world, otherwise, if it's just theoretical, it's hard to understand what the purpose is. So sometimes, my way of studying is to take a concept and to try to relate it to something real, to real life situations. I write things down, I'm not big on typing. Make cue cards, make condensed notes. I try to use different things. Yes. So in my biology course, I'll read the chapter before class and I'll make condensed notes. I'll go to class, I'll listen and I'll already know from the reading. And if she ever says something different from the book, then I'll jot it down. I'm not big on just reading things though, otherwise I get distracted. What really helps is highlighting, which is why I never return my books. As soon as I highlight something, it tells my brain, I need to remember this.

5. Do you think that learning about the history of science is going to be useful to your understanding of science?	Student L	Yes it is. Of course. Because we can see how they made their discoveries, and maybe that can give us ideas about how we can make new discoveries too. So it will be really different. Because in our time, everyhing has been invented. Well not everything, but everything we learn about. So most people work on things they already know was invented by someone else, they just incrementally improve it, but to make new discoveries... it's just really interesting to see how these people made these discoveries without knowing much. They had no technologies and yet they made discoveries. So we can learn some lessons from the past. And it'll be interesting for us to see that. And how they were living at the time. What I think is not that cool though, is that most people aren't really into the game. They are still thinking with their 21st century mindset, instead of really getting into the role and be in Rome in those years. They are some people who are engaged and who speak well, but some other students just read their texts and I just wanted to sleep... That's not how you do it! You have to entertain!
	Student N	- Very important. Because you need to understand science as well. You need to understand why things work in a certain way, like the laws of gravity, you know, Newton. Like who discovered that? How did they figure that out? And even, when you read Galileo's theories, like some of them are right, some of them are wrong, but you read them and you go 'OK, that makes sense'. So if you think of things and you want to know why and how that happened. You want to know the why and how. Because the past will show you how they've gotten to that conclusion. It's like for Psychology, I can't just be like 'Oh, I know how this works'. But is it a theory, is it like proven? Does it make sense? You know what I mean? - *Yes, absolutely. And hopefully this course will help you do that.*
	Student P	Not that useful, I'm going to say. Because in my everyday life, if I becoem an athletic therapist, what i'm going to need to know is what's in the body, how to perform CPR, keeping up to date with the most recent techniques and stuff. But at the same time, if I know, in the beginnings of science, how techniques have been discovered, I could understand how the new techniques today will be discovered.

	Student M	- Useful and at least keep an open mind, and being educated about the world in general. People should be like 'culturalized', you know, and not working in a bubble. So I feel like this is the general culture of our field, or like of all of our fields. Because when you're reading the textbook and you're like 'oh that's the history of microscopes' and you're talking about van Leeuwenhoek and Robert Hooke, and that is interesting, or we discovered the pasteurization process. Yeah, I'm always interested about learning these things. There's always a section in the textbook about these things, like the origins of this field. Or you know, in genetics, the pea plants, Mendel. That one has been analyzed again and again. But when you're going to genetics class and you're learning about all these people who learned, like this guy discovered the ratio of the nucleus, and you see the
		discoveries increase with the development in technology...And people are always like 'I don't want to learn that' but then I do. I have a friend who doesn't want to do Science college, like it's not her thing, type of thing. And then I have another friend, my best friends, and I'm telling her that in the Science college, I have to do the history and sociology of science and I've gotta take independent study projects in two fields that aren't my fields and she's like 'But the point of the university is to specialize', yeah, but I can't seem to explain to her that that's not everything. There's so many people who talk about branching out, like getting ideas from elsewhere, so if you don't look elsewhere, you're not going to get those ideas. And I feel like I'm bored doing just one subject for ever. I don't know, I'm already doing like a specialization or an honours in biology, 'that's not enough credits in biology? You want me to take like a minor in bio as well?' (laughs). At least I'm not doing electives in like...marketing or something. On some level it would be useful, as a scientist to market yourself and try and sell yourself, get like research grants and things, but I feel like that's something...you're going to get more from just practising that and doing it hands-on than from learning the terminology of all these things in a classroom. Like it's going to come anyway, I'd rather spend...Like I took a geology course! I liked it. I even took another one. I took one in Cegep and I took one here at Concordia. Like people say it's so boring, it's rocks, but it's the chemistry of the earth and the physics of the earth (laughs). And also, related to the course, how the chemistry of our earth makes us humans, versus aliens who might be different based on the chemistry and the geology of their planet.
	Student O	For sure. It's kind of random to just have that theory pop up. Like, what came before it? To bring it to that? With what we're doing now, Aristotle was saying "the earth is in the center" and then people after were taking his ideas, but were changing other things, and then someone said "well no the sun is in thecenter", so it's important to know, how everything came about.

	Student Y	Yeah. I never really thought about it before this class. I have always been really interested in history, because history is the foundation of everything, so it must be important for science. I just didn't know much about it before. I knew Galileo and Darwin and all these names, but I didn't really know about how a theory back then could have evolved into something so grand today.

Transcripts of the second interviews (2015-16 participants)

1. ***How much did you know about the history and philosophy of science, prior to this course?***	Student K	Before this course, I didn't know anything. Seriously, I don't read a lot of stuff from history, I usually read chemistry stuff or science stuff, but the history of science, I didn't know anything about it. Even Galileo.
	Student L	I knew nothing actually. It was really a good class for me because it helped me learn about it. I was not aware. Like I had taken some philosophy classes, but they weren't related to science.
	Student N	Not much at all. I was familiar with mostly Aristotle, from high school, but oth than that, not much at all.
	Student P	Practically nothing. I would say I had never heard about any of these scientific philosophers that we're talking about now.
	Student O	Well, I guess, I'm Greek so I guess, the whole thing with Aristotle, I kind of grew up with that, when I used to go to Greek school on Saturday. I learned about stuff like that, but not much I guess. I guess I knew more about Darwin...Galileo, I didn't study as in-depth as we did in Scol. So I guess not much yeah.

2. ***the GG, what did you think about it?***	Student K	Before the game, I didn't know what to expect. It was like unknown. I knew I was going to have fun, I knew I was going to learn a lot. I was looking forward to learning about philosophy and about the history of science. But seriously, I didn't know what it was going to be.

	Student L	Actually, I always feel nervous before an oral. I just don't show it and I pass over it to be comfortable in front of the class. But I always feel that scary emotion inside of me. I just don't let it stop me.
	Student N	OK (laughs) the GG was interesting, but as we mentioned earlier, it was a lot of work, and we maybe should have had more time to prepare for the presentations. But at the same time, it made us see the different views, not just read about it, but also act it and see it face front. But I found that, the only bad part about it was that we weren't allowed to have questions, so someone would say something and you disagree with it but you were sitting down and you can't just be like 'yeah but no it's this!'. So in a way, it's good, because a lot of people, like myself, I hated going up and presenting in front, because I'm really nervous, and I was kind of glad nobody attacked me, but at the same time, it changes when you're sitting and you want to attack the person up there. It wasn't interactive enough among students. But the whole game, with the learning aspect, that was pretty well formulated.
	Student P	It was interesting to see how our group would try to portray the views at the time. Because the views today are so much...not advanced but so much more developed and evolved. So that was interesting. I didn't particularly like writing the papers, I have to say. Because, as moderates, we always had to find like "welll you know the conservatives were kind of right, but the lancetians too". At times I also found that the instructions from our teacher were a little bit too liberal. so my second paper, it was a day where there were two meetings, the first one was the party at Prince Cessi's and the other one was like a holy office tribunal, and he hadn't really mentioned that Prince Cessi was really like free ideas, and so, me and my partner, because we were sharing a character, we kinda did a really formal presentation while we were at Prince Cessi's, so I kinda sped through my presentation to get to the poem, which was a little more artistic.
	Student O	Oh it was different! But I had fun. I guess you learned more about it when you're more kind of interacting with the audience, I guess. And, you know, we were the conservative team and they were the Linceans so we had to really focus on our role, it's not just like the teacher lecturing, you know 'this is what they did', we really had to immerse ourselves kind of thing in the roles. I really liked that. And you did learn quite a lot about what they went through back then, you had to be careful what you were studying and what you put out in the world about their discoveries. It was a lot of fun (laughs).

3. *did you find that the GG was useful to understand how science works?*	Student K	- Yeah. It makes you think about how people used to think and how science has evolved. Just like, it makes you more open-minded to think about...anything can affect science, like religion or sociocultural aspects. It's good to have a notion of what they used to do in those times. You can like use it to think about, when you're trying to solve a problem, you can approach the problem how they used to approach the problem and maybe you're going to have an answer. You never know. *And do you think learning about this is still relevant today?*

		- (pause) It's a good question. Yeah I think it's relevant, as I said, it gives you another approach to science, I think. It's pretty much like learning basic maths. They used basic math at the beginning of science, and it has evolved, and it's always useful to think about basic maths, like calculus for example. It's definitely useful to think about the basics of science, and then to build upon them.
	Student L	Absolutely! Yeah, it was really awesome. For one, I didn't know about Galileo, I didn't know anything about his trial, I didn't know hwat he was trying to convince the people, so I learned about him. So that's really cool because that's really important cultural knowledge. It helped me understand how science was perceived in the old times. how the Church was really involved in science and how the Church was really ruling science and deciding which theories were good and which weren't, so science was not as free as it is now. And it took them a lot of courage to stand by their theories and really push them forward. So that is really impressive when we think about it. Because right now, any scientist can just come up with a new theory and present it and we won't put him in jail or kill him.
	Student N	Yes! Definitely, because it opens your views to see like, because people think that, I find that what I thought coming into this that theories were based on this, were tested and this is what we know today, but the GG told you how wrong we were from the beginning.
	Student P	Yes I do. Like today we've accepted some of Galileo's theories, but at the time it was completely unthinkable, like when Aristotle presented all of his theories. SO we can really see throughout the game how society is a huge factor in discoveries and science and we've seen this also in the reflection papers, so for sure it's not 'black and white', it's like, for sure whoever is influential at the time has a say and it will change the evolution of a certain idea. That was the case for the Holy office, that was a big factor in whether or not Galileo's theories were accepted at the time.

	Student M	(pause) Yes, if we go into the broader picture. Science isn't done in a vacuum. It always occurs in the context of social factors and history, and this truly shows us an embodiment of what happened historically in science, how social factors influence science. You can see it by sort of living it, as we lived out the game. So, for sure. You have to remember that science does play out on the human game-board. I liked that we immersed ourselves in this completely.
	Student O	- Oh my gosh, yes! Well, again, just to like, at the beginning, I didn't really know about how it came about, our theory of the universe and stuff. So really, playing the part, the Church, and Aristotle...how they had their ideas, and then after Copernicus came along and he fixed up the theory and then Galileo came along and fixed it some more, so you really saw the history of past theories and how they evolved. Yeah, it was, again, I found it better
		than the teacher talking about it in class, like you really saw how they were like back then.

4. *in your view how does science work? More specifically, how do scientific theories come about and how do new theories replace old ones?*	Student K	- Well, before the course, I used to think that science was super straightforward, not like a golem. I didn't think that science was like this golem. I was like well science is straightforward, well I also think that, think science is true, regardless of whether you believe it or not, but now my picture of science is that it can be affected by religion, by like society, where you live...It's like a golem actually. That reading was actually...I realized science is actually like messy and clumsy, you know. Sometimes it' affected by politics or location, even the way of doing science. - *OK and so overall, would you say that your view of science has changed over the semester?* - Yeah. For sure. Now I see science with completely different eyes. I see science as so...vulnerable. (laughs).
	Student L	- The paradigms? So, it's by, they are constrained by social pressures, they create, there are many factors, like historical and social factors that affect the science process, and there can also be a bias, in terms of social class for example: not all social classes have access to knowledge, so they cannot give their contribution to science. Also women, the gender bias, for many years, women weren't allowed to be part of scientific fields, so that

		would have decreased also the number of new theories and new paradigms created, and now with the current paradigm, most of the students choose their major and then in their masters and phd, they are working on one of the paradigms and they don't cross links with the other ones; so there is this exclusivity of the paradigm, which also reduces the advancement of science. And sometimes, when we find that a paradigm isn't good, we discard it entirely, without thinking that there can be some part of it that is good and on which we can work to create a new paradigm. It shouldn't be discarded. It should only be put aside and worked on and referred to sometimes, while working on the new paradigm. This is in most fields like physics and mathematics, but I don't think it's the case in psychology or... - What do you think it is in biology, your discipline, for instance? - In biology it's a continuation, so we never discard. Yeah that's a really important principle. When we find something to be wrong, we don't say it's a hoax, we say that 'maybe it's wrong because it's incomplete. So we set i aside, until new evidence compels you to look into it again. - OK so do you think this was an appropriate amount of time for a university course? Yeah, it was.

	Student P	- (laughs) Well, science is a much more complicated process than I thought! Because it's not only creating an experiment and a hypothesis and testing things and getting results and then putting those results into words. It's not like that. And I think the biggest factor is our own society, and how the big influential thinkers have opinions. So I think our three, or one of the last reflection papers, like that was really one of the main topics, and like Galileo for example, it's like his theories – I don't know if this is completely correct, don't quote me on this – but a lot of things he said were correct but society didn't really let him express himself, because his views were contrary to the views at the time. So that plays a big role in science I think theories come about from finding a problem and needing to have a solution. And say someone finds a result, and if that result is like one result versus 50 other results that have proven a certain theory, it won't really come up, but if more and more flaws are found in the previous theory and more and more arguments come about in the new theory, it could come, but again if in society there is something like religion, like in Galileo's case, it was so strong, it won't come, even if the scientific proofs are there. That's very much like the paradigm. - *And so do you think that your views about this have changed over the semester?* - Definitely. I'm much more educated about it, I find (laughs). - *Can you try to describe in what ways it has changed?* - - I can see that there is so much more scientists are up against in order to find a theory and prove it. And different factors, religious factors, societal factors, but there's also other factors like women VS men, like obviously there is a big stereotype, men being more predominant in science than women, so there's that too.

	Student M	- (pause) That's something that's still... (pause) Part of with Popper was, you get to see what makes a good scientific theory, but we never really explored, I feel, where they originated from, because I still feel like you hear, it's like people who manage to think outside the box. Like now science is all about interdisciplinary studies, or using, like engineers who end up working in some other field. I think that theories...I don't know if you can sit down and ask "oh how does this work?". You have to explore. You can't just come up with "maybe this is the mechanism for that". You're shaped by the knowledge we're already aware of. You'll think "maybe this mechanism is like that mechanism". You won't be able to come up with completely off-the-wall theory, unless you're, I guess if you're in a crisis period. And that's where like Einstein was. How his new paradigm and theory of physics was so different. I guess that depends on where you are on the paradigm timeline. Because, in the normal science, it would be based on our knowledge, find similarities, whereas if you're in crisis, you're going to start looking for weird explanations, until someone comes up with the new paradigm. *Did you always have that view? Or has that changed over the semester?* - I don't know. I never actually thought of that question. I think my thoughts before the class were about how. I don't know if I would have been able to answer that question the same way at all. I think it would have been different. As for the other part of your questions, new theories replacing older ones...obviously my answer has to do with paradigms. Before that, three months ago, how would I have answered that question? I probably would have said that an accumulation of evidence for the new theory makes it better accepted. But sometimes, you're aware that the evidence, you're looking at the data, and you can pull so many different conclusions from the data, so you can pull support for Einstein from the same data that gives support to Newton. So yeah.
	Student O	- Oh my gosh, well I had put in on my concept map. For sure, you have to be objective, you can't...you could I guess pull ideas out of thin air if you see something, but you can't start experimenting, you have to like have your ideas on paper, your hypotheses, and obviously, don't, you could be biased you know, thinking 'Oh I'm pretty sure I'm going to get this result', put your ideas down, do your experiment and then see if it backs it up or not. So yeah, it has to be systematic, you can't randomly do experiments 'I think I'm correct!' and just publish it. There are many steps to it. *And so, did your ideas of how science works change throughout the semester?* - Yeah. I've always been in the sciences and in college, we used to do like our chemistry labs and used to write lab reports, but I guess I never realized, they never really taught us the proper way to do science. Like yeah, we would have our procedure and we'd follow it, but, even sometimes in my lab reports, I'd cheat. I'd say I put this much substance

		and that kind of thing. And oh my gosh, you cannot do that in real life (laughs) It also has to be falsifiable. Yeah.
5. ***do you think RW is a useful tool to understand how science works?***	Student K	- It was pretty much about the same thing as the GG. They, the teacher tried to get us to think about how to approach science and how does science work, like the different aspects that affect science. - *OK, and why do you think the professor has given you this writing activity?* - Oh because maybe sometimes you read it, you find it really interesting and you're like "OK, I want to know more about this" but then you forget. But writing the reflection papers, it allows you to analyse it and think more about it, and at the end it stays in your mind. And you have the paper and you can go back to it if you ever need them.
	Student L	Yeah a lot, oh my god. Because there were a lot of things I never thought about, I didn't know about. And those things were revealed to me through the readings and it's really important in science, not only the process of science, but also all the exterior pressures that affect science and that we aren't even aware of. We don't know they exist. The social aspect of science was very relevant in those readings. But I still think he could have chosen shorter readings.
	Student N	To show us also over the course of history how science has evolved. And how science was interpreted through different theories, like paradigms, and how to prove science. Also to make us reflect about it. Because if you gave a lecture, like a one-day lecture, people might retain it or people might not, but if you're giving them the independence to read it and to actually think about it and then t o come into class to discuss it, then you're involving the students more, you know what I mean? To actually understand what you want to portray in the course. I find that when I do lectures, I hardly listen, I only understand when I go home, i I crack open the textbook and I teach myself, and that's kind of what he was trying to do.

	Student P	- Absolutely. I think it should be done in more classes. - *OK! I actually have a question about this coming up. So why do you think this?* - Because I think there was like, there is this graph that exists, you know 'you retain 10% of what you read and you retain 90 or 95% of what you teach'. So reading is really low on that skill because your brain is not completely involved in what you're doing, and I know that personally when I read these texts, I catch myself, like every paragraph, thinking of something else and you're like 'I don't remember the last lines'. But writing is a totally different story, because you're really involved and reading you don't have to know things, but when you're doing this reflective paper, that's one of the main points of it.
	Student M	- The readings are to learn and understand and start to discover – because this is just a small portion of what philosophy of science is –

		and they improve, it's sort of reshaping what the image of science is, in my head. Because the science that has been taught to us is different from the one that I will one day, hopefully, be doing in the lab? - *In what way?* - Well when you're doing an experiment in high-school, it's like things are provided for you. You just do the reaction and observe. Whereas in reality, when you're in a lab, you don't know what you'll be looking for. You're the one who has to pose the question. And all the Popper and Khun, well lot of Popper for that, that will shape how you create hypotheses and decide things later. It's completely changed, how we view science. I don't know if you're going to have our concept maps, but I expose that a little bit there. But initially, when asked "what is science?", before it'd be like "the scientific method" and all these departments , all these fields of science, and then it has changed, including the form of science instead of just the content of science. That really opened my eyes, expanded my view.
	Student O	Again, it's not just a teacher teaching it to you. For sure, I mean it just reinforces, it's like studying for a test: you won't just read it once, you know, I guess by rereading it, by checking the definitions and then just writing it and relating that to your life, it forces you to understand better you know, what science is and what the author was trying to portray to the reader.
6. what advice would you have for a new student registering for this course?	Student K	For sure. Because it challenged you to think things you've never thought before. At least me I had never thought them before. Like analyse them and put some time into it. And it's not easy stuff, it's not like maths, 1+1 = 2. It's like this point of view is because of, is affected by politics, by different people, how science is constructed, how our universe is constructed.

	Student L	Don't pick the Galileo team, the Lancetian. You will lose. Pick the conservatives, it will increase your chances. About the readings, you don't really have to do them entirely. You can sometimes skim, the teacher will give you all of your points. You don't have to put too much time into it. And do something interesting. You have an audience, you have to entertain them. You can't be in front and just read off your paper, everyone will fall asleep. You want someone presenting to be interesting, so be it! That's the tip I would give. Oh and be nice with your fellow students, you can help one another.
	Student N	OK, make time (laughs), make lots of time. Put in the time required, because you want those good grades, you know hwat I mean? They are easy grades to get, it's an easy grade to get at the end of the day, just that, don't expect to come in here and do a couple of quizzes, a couple of papers and pass the class, not doing any readings. You have to put the time into it.
	Student P	I would say, like, you kind of have to have an open mind in this class. Because you have to be ready to be for, against, you have to be ready to be the public,
		the judges, and yeah I think that's the most important point. Because the rest, like writing, it's really OK.
	Student O	Hmm...don't be nervous! (laughs). Everyone is super friendly. It might feel overwhelming, I know in the beginning for myself it was like 'oh my gosh I have to write so many papers', but it's like...it's not like you're writing about random stuff. You're also learning, it's part of your character, so if you get immersed in your character, you might have a more fun time and an easier time to write your papers. And again, in the RW, it's not like 'oh my gosh what the hell is this?', it's more like 'oh shit, you're actually learning interesting stuff that does affect you and will affect you later on if you stay in the sciences. Yeah, so 'don't be nervous' and 'you'll actually learn a lot'.