

TEACHING THE NATURE OF SCIENCE THROUGH
HISTORY AND PSEUDOSCIENCE

by

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DEDICATION

This work is dedicated to my wife Shelley. The prospect of undertaking a task such as this is a daunting one, and not always easy for someone this late in his career. It was through her urging that I decided to pursue this in the first place and with her continued encouragement and support that I have been able to complete it.

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ABSTRACT

Students in high school science classes often have a poor grasp of what the process of science actually entails. The Nature of Science (NOS) needs to be taught explicitly but teachers often do not do so because it is an area often misunderstood and poorly presented in textbooks and curricula. This study was conducted to determine the effectiveness of teaching the NOS through the use of a series of brief lessons on topics from history and pseudoscience. Twelve intervention lessons were presented in a variety of formats over a nine week period to students in three high school chemistry classes. A total of 56 students of a range of academic abilities participated in the study. Data collection instruments were developed to measure understanding of eight defined aspects of the NOS as well as student engagement and attitudes toward studying chemistry. Students were also interviewed and observed during the lessons. At the conclusion of the research students demonstrated an increased and more robust understanding of all aspects of the NOS. Data also showed that the lessons in history and pseudoscience were effective for student engagement. The lessons were regarded as interesting and fun and helped provide context for curricular material.

INTRODUCTION AND BACKGROUND

As a science educator I have always felt one of my most important responsibilities was to instill in students an understanding of the process of science and how to look at the world through scientific eyes. In today's technological society, possibly more than ever, there is a need for students to be able to think critically. Science education has traditionally focused on teaching students about *the* Scientific Method, as if there were a single common strategy employed by the entire scientific community. The *whole* Nature of Science (NOS) has been misunderstood by teachers and ignored by textbooks, and has as a consequence not often been covered well in our classrooms (Ellerton, 2012). This disconnect with the way science is actually done has troubled me throughout my career.

I teach at North Battleford Comprehensive High School, one of three high schools in our community in the west-central part of the province of Saskatchewan. The school draws from an area with a population of about 19,000 which includes the town of Battleford and the city of North Battleford, separated by the North Saskatchewan River (Statistics Canada, 2014). The rural area surrounding the Battlefords also includes seven First Nations reserves; as a result about 21% of the city's population is of Aboriginal ancestry (City-Data, 2014). The city is the service hub for a large agricultural community and as such the largest employment sectors are healthcare, retail trade and business services, with the oil and gas sector becoming increasingly important. Unfortunately, the Battlefords community is faced with very high levels of poverty, a significant transient population and low levels of adult education compared with the Canadian average

(Collie, 2013). All of these combined demographic factors result in the city having the highest crime rate in the country.

With students drawn from all areas of the community the Comprehensive High School includes a very wide range of socioeconomic backgrounds and experiences all of the accompanying challenges. The school population is diverse, with roughly 43% of students being of First Nations ancestry and a smaller but growing number of eastern European, Asian and Philippine immigrants who are learning English as a second language (Principal L. Heinemann, personal communication, November 25, 2014). Our community's composition produces a school population that can be very fluid; in the fall of 2014 we began with nearly 1000 students registered in grades 8 to 12, and by late in the second semester the population had dwindled to under 800. Because of our demographics we must also deal with a wide range of family issues and student needs that manifest themselves in terms of student behavior and performance. Poor attendance and poor student engagement are endemic problems throughout our school.

My teaching load consists entirely of senior chemistry. Each semester I teach 1 class each of grade 11 and 12 chemistry along with 1 grade 11 and 1 grade 12 International Baccalaureate Programme (IB) chemistry classes who are learning at an enriched level. All of the chemistry courses are academic electives and tend to attract more academically inclined students, so I therefore see fewer student problems than some of my colleagues.

As part of the normal IB curriculum renewal cycle a newly developed chemistry syllabus was introduced in February 2014 for use beginning in the fall of 2014. This new

syllabus included for the first time the Nature of Science as an overarching theme to be addressed throughout the course. Aspects of the NOS were referenced for each sub-topic in the syllabus (IBO, 2014).

When I received the IB syllabus this new theme presented me with the challenge of finding teaching strategies to address the NOS requirement. Over the past few years I have occasionally incorporated historical anecdotes in my chemistry lessons to show how the science has developed, and I have often addressed pseudoscientific topics as a way to teach critical thinking skills. It seemed natural to combine these to produce the focus of my action research: to examine the effectiveness of using topics from the history of science and pseudoscience to teach the nature of science. This focus was divided into a main focus and two sub-questions that were examined:

- Main question: Does the use of pseudoscience and history of science lessons improve students' understanding of the nature of science?
- Sub question 1: Does the use of pseudoscience and history of science lessons improve student engagement in chemistry classes?
- Sub question 2: Does the use of pseudoscience and history of science lessons improve attitudes toward studying chemistry?

CONCEPTUAL FRAMEWORK

One of the most important goals of science education is to instill in students an understanding of the actual enterprise of science. This appreciation for the Nature of Science (NOS) has for many decades been repeatedly cited as an essential central theme of science teaching (Abd-el-Khalick, Bell & Lederman, 1998; Dogan, Cakiroglu, Bilican

& Cavus, 2103; Iqbal, Azam, & Rana, 2009). According to Peters-Burton and Baynard (2013) all major curriculum reform initiatives around the world over the past 20 years have called for an increased emphasis to be placed on the NOS, and this need for more NOS teaching has not diminished. Project 2061, the National Science Education Standards in the 1990's, and most recently the Next Generation Science Standards in the US and the new International Baccalaureate science curricula, all include a major focus on the NOS (IBO, 2014; Iqbal et al., 2009; Matthews, 2002; NGSS Lead States, 2013).

There is a clear and growing consensus of opinion in the scientific community supporting the importance of teaching the NOS in all science courses, both K-12 and undergraduate. The call for an increased emphasis on the NOS applies to elementary students as well but is even more important for high school students because their greater cognitive development allows them the necessary depth of understanding (Abd-el-Khalick & Lederman, 2000).

Despite the significance afforded to the teaching of the NOS, study after study has shown students continue to have a poor grasp of its concepts (Afonso & Gilbert, 2009; Khishfe & Abd-el-Khalick, 2002; Molé, 2006). A 2004 study by the International Association for the Evaluation of Educational Achievement indicated that American students have lower scientific literacy scores than those in other countries (Molé, 2006). As reported by Eve (2007), the more recent emphasis placed on the NOS has improved student understanding slightly, but it is still far below an acceptable level. This failure of science education to instill an understanding of the practices and processes of science has greater implications as the need for a scientifically literate population in our modern

world grows. As a society we are increasingly dependent on science and technology, and the need for critical thinking and an understanding of the NOS has never been greater (Osborne, Collins, Ratcliffe, Millar & Duschl, 2003; Preece & Baxter, 2010; Schmaltz & Lilienfeld, 2014).

There are several hurdles that must be overcome if this goal of NOS literacy is to be achieved. First, the scientific endeavor is in itself a very difficult thing to define in simple terms. In a talk given to science teachers Nobel physicist Richard Feynman (1969) declared even he was unable to provide a definition. As a result it has been difficult to reach a consensus on what should be included as the NOS. Couple this with the fact that definitions of the NOS have changed over time, and the situation becomes even more complex (McComas, 1998; Peters-Burton & Baynard, 2013).

A great deal of work has been done with the goal of arriving at a definition of the NOS for the purpose of teaching it, but that has been difficult to achieve and in fact has created some controversy (Allchin, Andersen & Nielsen, 2014). McComas, Clough and Almazroa (2002) developed a comprehensive definition of the NOS that was well received, but another definition developed at roughly the same time has also received a great deal of support and has been the basis for many of the instruments that have been developed to measure NOS literacy (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002). This research has been reinforced and further developed by Osborne et al. (2003) who established a consensus opinion of what should be taught as the NOS. This research involved a thorough examination of the research, curriculum initiatives, and a Delphi

study of opinions in the expert community. This widely accepted definition of the NOS has seven aspects (Lederman et al, 2002):

1. The Empirical Nature of Scientific Knowledge
2. Scientific Theories and Laws
3. The Creative and Imaginative Nature of Scientific Knowledge
4. The Theory Laden Nature of Scientific Knowledge
5. The Social and Cultural Embeddedness of Scientific Knowledge
6. The Myth of the Scientific Method
7. The Tentative Nature of Scientific Knowledge.

A second obstacle facing NOS education is that once a consensus is reached on what *should* be taught as the NOS, teachers still generally do not teach it well. The NOS is complex and not particularly accessible in terms of teaching because it crosses many academic disciplines (McComas, 2008). The NOS is also often overlooked by teachers and not specifically addressed at all. Research by Gallucci (2009) and Vlaardingerbroek (2011) found that teachers often do not teach the NOS because it has not been part of science curricula. If not explicitly placed in the curriculum, teachers will avoid teaching it because they do not have time for including perceived extras in their courses. The culmination of the recent research has been that the NOS has finally been included as a significant piece in the newest curriculum initiatives. The new IB science curricula have incorporated the NOS as an overarching theme, and the NOS has been included as an appendix to the Next Generation Science Standards, intended not as a fourth dimension

of the Standards but rather as a foundation on which to build instruction in the sciences (IBO, 2014; NGSS Lead States, 2013).

Another problem is the difficulty of teaching the NOS once teachers have the motivation to teach it. According to Viana and Porto (2013) there is little teaching material available, and without readily available materials teachers find the NOS a difficult topic to address. In an examination of the most widely used high school chemistry text books, Abd-el-Khalick, Waters and Le (2008) found the texts had uniformly poor coverage of the NOS, if any at all. They also acknowledged that the textbook essentially becomes the curriculum in many classrooms, and observed this was another major reason for the poor coverage of the NOS in schools.

Several studies have also shown that teachers themselves often have a poor understanding of the NOS (Abd-el-Khalik et al., 1998; Abd-el-Khalick & Lederman 2000; Dogan et al., 2013). Teachers have misconceptions about what the NOS entails, and often pass these misconceptions on to their students because they haven't had adequate training in the NOS (Dogan, 2013). Abd-el-Khalick et al. (1998) acknowledged that the teachers' own knowledge of the NOS does not translate well to their students regardless, and an effective means of delivering the NOS material to students is necessary.

It must also be noted that simply providing science education does not ensure an adequate understanding of the NOS. Science literacy is complicated and is subject to many influences from popular culture. Even though initiatives like Project 2061 in the U.S. have brought some changes to the way science is taught and have improved

scientific literacy somewhat, the situation remains very poor (Eve, 2007). Both Johnson (2004) and Walker (2002) concluded there is no correlation between education and skepticism. Educating people about science does not necessarily produce improvements in critical thinking or correspond to decreased belief in pseudoscience. Research reported by Preece and Baxter (2000) showed that although older high school students are less gullible toward pseudoscience than younger students, even these older students are very gullible, and only a minority at any age is very skeptical.

The research shows clearly that in order to produce a deep understanding of the NOS it must be taught explicitly. There are different approaches to teaching the NOS, but regardless of the method, the learning needs to be contextualized and taught directly (Afonso & Gilbert, 2009; Allchin et al., 2014; Stansfield, 2013).

The most commonly recommended approach for teaching the NOS is through history. Because the NOS is closely tied to the history of science (HOS) there is a natural tendency to use historical cases to illustrate aspects of the NOS, and in fact it is considered by many to be the preferred approach (Allchin 2012, Kipnis 2002, McComas 2008). Kragh (1992) has suggested a historical perspective is essential for an understanding of science. The historical context is especially well suited for illustrating that scientific knowledge is tentative and fluid, not static.

Kipnis (2002) and Slezak (1994) both noted that using the HOS allows the teacher to intertwine teaching NOS with the rest of the class content and makes the content more stimulating and engaging to students. They contend the NOS must be taught simultaneously with science content in order to give it a meaningful context. Indeed,

there is evidence that using case studies from the HOS within the normal curriculum can increase understanding of the NOS even without it being explicitly taught (Solomon, Duveen & Scot, 1992).

Another benefit of using history to teach the NOS is that historical examples make the fairly abstract NOS concepts concrete for students. The ready availability of case studies and stories of discovery from the HOS helps solve the problem of the lack of materials to teach NOS as well. Historical case studies are interesting to students and aid in engagement (McComas, 2008).

One of the most important reasons cited for improving teaching of the NOS is to improve critical thinking skills, so students may be better able to deal with the socioscientific issues we face in our modern world (Allchin et al., 2014). There is a vast array of scientific information available today. This brings with it an ever-increasing volume of pseudoscientific information, and students often do not have the skills to separate the good from the bad. The level of scientific literacy of the general population is very low, and pseudoscientific beliefs are becoming ubiquitous even among those with a science education as well as among non-science majors (Schmaltz & Lilienfeld, 2014). Indeed, pseudoscientific ideas are even creeping into the curriculum (Novella, 2012). The non-scientific and irrational thinking that results in pseudoscientific beliefs constitutes what has often been called a threat to science and poses risks for our populace (Afonso & Gilbert, 2010; Johnson & Pigliucci, 2004; Stansfield, 2013). Science educators need to confront this problem by trying to combat it directly rather than ignore it and hope the pseudosciences fall out of favor (Allchin, 2012; Calvin, 2009;

Vlaardingerbroek, 2011). To do this we need to instill a sense of what has been called scientific skepticism in our students (Schmaltz & Lilienfeld, 2014).

There is a consensus of opinion among researchers that pseudoscience is effectively countered by teaching the NOS, while at the same time pseudoscience is an excellent vehicle to use in teaching the NOS. Critical thinking skills and skepticism are important aspects of the NOS, and therefore the ability to examine and evaluate pseudoscientific claims is directly correlated with an understanding of the NOS.

Calvin (2009) and Efthimiou (2006) have found case studies from pseudoscience provide an excellent context for teaching critical thinking, skepticism and the NOS. The material is often familiar to students because these pseudoscientific ideas are common in our society, and therefore very appealing and well received. Critical thinking skills are also taught more easily using ideas that fall into the grey areas pseudoscience provides. Several studies employing pseudoscience as a device to teach science have shown significant positive effects on student understanding of science research methods as well as critical thinking skills (Ashton, 2008; McLean & Miller, 2010; Wesp, 1998).

Skepticism towards pseudoscience increased also. It is significant as well that these gains in critical thinking skills are internalized because they transfer to other unrelated issues. The flaws in reasoning exhibited in these accounts are both accessible to students' understanding and provide high levels of engagement.

It must be noted, however, that just teaching students about the NOS does not necessarily improve skepticism towards pseudoscience (Schmaltz & Lilienfeld, 2014). These non-scientific beliefs may persist even after students have learned the relevant

science. Preece and Baxter (2010) urge that teachers should explicitly confront their students' superstitions and pseudoscientific beliefs as a way to develop skepticism in their students. Students' enthusiasm for these topics provides a tremendous opportunity for engagement in scientific thought.

METHODOLOGY

The primary goal of this classroom research project was to increase students' overall understanding of the Nature of Science (NOS). According to the literature the NOS must be explicitly taught in order for students to develop an appreciation for it. It is a difficult area for teachers to cover, but history and pseudoscience are appropriate vehicles with which to teach it. A historical context aids student engagement and provides a natural context, while pseudoscientific case studies provide an accessible and interesting way to teach critical thinking along with the NOS. The treatment of this study was based on the action research model and involved teaching the NOS using historical and pseudoscientific anecdotes and case studies over the course of a large part of one semester. Once the students' baseline knowledge of the NOS was established, lessons explicitly addressing aspects of the NOS were given through the use of these case studies. At the close of the intervention period the students' understanding of the NOS was reassessed.

For the purposes of this study a definition of the NOS was developed based on the sources most relevant to the situation. The widely accepted definition by Lederman et al. (2002) has seven aspects, and when it was compared with the definitions from the recent curriculum initiatives, it was found that they could be comfortably amalgamated (IBO,

2014; NGSS Lead States, 2013). The result was an eight-aspect definition which I felt adequately captured the scope and spirit of the NOS in all three descriptions (Table 1).

Table 1
Definition of the Nature of Science for the Purposes of This Study

Aspects	Details
1. Tentativeness	Scientific knowledge is tentative and always subject to change in light of new evidence.
2. Empirically-Based	Scientific knowledge is empirically based. It is based on data and rooted in repeatable observations and measurements of natural phenomena.
3. Methods	There is no single scientific method followed by all scientists. Scientific investigations use a variety of methods.
4. Models, Laws and Theories	Scientists create models to conceptualize natural phenomena. Scientific theories are well-substantiated explanations of natural phenomena. Laws are descriptions of natural phenomena, often mathematical.
5. Creativity and Imagination	Scientists use their creativity and imagination throughout investigations. Serendipity is often an important factor in science.
6. Logic, Consistency and Critical Thinking	Scientific knowledge is based on a common logic and assumes an order and consistency in natural phenomena. Critical thinking skills are essential.
7. Human Endeavor	Science is a human endeavor. It is collaborative, international and multidisciplinary. Observations and interpretations may vary because of prior knowledge and perspectives.
8. Culture and Society	Science is embedded in culture and society. Culture determines what and how science is conducted and how it is judged.

The interventions were performed in my grade 11 and 12 chemistry classes. The grade 11 group consisted of 38 students in two classes, one IB class taking an enriched grade 12 chemistry curriculum and one taking the regular grade 11 curriculum. There was also one grade 12 class consisting of 24 students studying the standard grade 12 chemistry curriculum. There were 34 female and 28 male students involved, representing

the broad demographic range typical of our school and a wide range of academic abilities. The study began in the first week of the second semester in February 2015 and continued for approximately nine weeks. This timeframe was chosen to provide the maximum possible duration for the study, and therefore the largest number of interventions possible, while not interfering with end-of-semester review.

The research methodology for this project received an exemption by Montana State University's Institutional Review Board and compliance for working with human subjects was maintained (Appendix H). The school and school division administrations were also informed of the details of the study and granted their permission.

A total of 12 intervention lessons were presented to students over the course of this treatment period, each based on a particular case or anecdote. Six of these cases were stories from the history of science, while the other six were topics from pseudoscience, and each targeted at least one aspect of the NOS (Table 2; Appendix A).

Table 2
List of Intervention Lessons

History Lessons	Pseudoscience Lessons
1. Priestley and the Discovery of Oxygen.	1. Astrology and Horoscopes
2. What Can You Do With Coal Tar?	2. Homeopathic Medicines
3. The Manhattan Project and the Creation of New Elements.	3. The Anti-Vaccine Movement
4. The Model of the Atom (Grade 11)/The Discovery of Fullerenes (Grade 12)	4. PowerBands and Q-Ray Bracelets
5. From Radar to Radarange	5. Dowsing
6. The Legacy of Thomas Midgeley	6. Reiki and Therapeutic Touch

The cases were presented in a variety of formats such as articles for the students to read, video clips, PowerPoint presentations and demonstrations. The lessons were generally brief, taking 10 to 15 minutes, and at the end of each lesson the relevant NOS aspects were outlined. The first intervention lesson for all classes was a history lesson which illustrated all aspects of the NOS so that the full definition could be presented. Each student also received a hard copy of the aspects of the definition of the NOS.

In the first two classes of the semester, before interventions began, all students took the Views About Science Questionnaire in order to establish a pre-treatment baseline for their understanding of the nature of science (Appendix B). This questionnaire was designed to determine students' understanding of the aspects of the NOS, and was constructed by adapting items from well-established and validated instruments and adding some new items created to suit this research (Lederman et al., 2002; Liang et al., 2006; Park, Nielsen & Woodruff, 2014).

The Views About Science Questionnaire was a Likert style questionnaire and allowed students to respond to statements designed to address specific aspects of the NOS in terms of their degree of agreement with the statement. Three to five statements targeted each aspect of the NOS. The responses were assigned values on a four point scale, with 4 representing either *Agree* or *Disagree* depending on whether the positive or negative indicated a strong understanding, and 1 indicating the weakest understanding of the NOS. This questionnaire was administered again following completion of the treatment.

Being non-parametric, the data for this instrument was analyzed by calculating mean and median values for each statement. Pre-test and post-test means were calculated for each Likert scale question group and a Wilcoxon Rank Sum test (Mann-Whitney U Test) was applied to test for significance. Frequencies for each response level were also calculated in order to compare pre- and post-tests.

Additional baseline data was provided by the NOS Misconception Probe (Pre) (Appendix C). This instrument used a brief fictitious story to measure students' understanding of the NOS in terms of a common misconception about the nature of science (Deng, Chai, Tsai & Lin, 2014). The instrument asked students to demonstrate their knowledge about what *law* and *theory* meant in science. This probe was used to generate qualitative data and in addition the responses to this instrument were quantified by evaluating them on a four point scale. The statements were assigned scores of 1, representing *little or no understanding*, 2 denoting *some understanding*, 3 indicating a *substantial understanding* and 4 denoting a *complete understanding* of the concepts involved (Table 3).

At the close of the treatment period the Misconception Probe (Post) was administered (Appendix D). This was a similar probe employing a different story that illustrated another common student misconception about the scientific method (Deng et al., 2014). With this instrument students had to demonstrate their understanding that science does not proceed by one particular method. The Misconception Probe (Post) was again evaluated on a four-point scale.

Table 3.
Scoring Rubric for Misconception Probes

Score:	4	3	2	1
Misconception Probe Pre-test: “The Theory Hypothesis”	Steve’s opinion with justification and understanding of the tentativeness of scientific knowledge.	Steve’s opinion without justification; Timmy’s opinion with indication of tentativeness of scientific knowledge	Timmy’s opinion; theory may be correct, when proven becomes a law.	Jimmy’s opinion; a theory is a guess.
Misconception Probe Post-test: “The Scientific Method?”	Jimmy’s opinion with justification showing understanding that scientists use many methods and think creatively.	Jimmy’s opinion without justification.	Steve’s opinion; scientific method but interpretations vary.	Timmy’s opinion; all scientists follow one method.

Frequencies for different levels of understanding and mean scores of pre- and post-treatment responses were calculated, and a Wilcoxon Rank Sum test was again used to test for significance.

The Views About Science – Open-Ended Questionnaire was a third data source (Appendix E). This instrument was based on items from the well-established and validated Views About Science Inventory (VASI) and Views On Science Inventory (VOSI) questionnaires with modifications and additions (Lederman et al., 2014). Students were asked to answer each question to the best of their abilities with clarification provided when requested. This instrument was administered to students a second time after the treatment period and the pre- and post-treatment results were compared.

To analyze these questionnaires the answers were considered as a whole to give a more comprehensive sense of each student's understanding of the NOS. The questionnaires were scored on a 1-4 scale, with a score of 1 indicating that the student had a very poor or rudimentary understanding of the NOS. A questionnaire indicating a basic understanding of some NOS aspects received a score of 2. A score of 3 was awarded to questionnaires that showed a more fully-developed awareness of the NOS, deficient only in understanding subtler aspects, while a questionnaire showing that the student had a very complete understanding of all the NOS aspects received a score of 4. Mean scores were compared using the Wilcoxon Rank Sum test, and frequencies for each score were calculated for comparison.

Data were also needed to answer the secondary focus questions regarding student engagement and attitudes. To this end, the Chemistry Attitudes Questionnaire was developed, consisting of 30 Likert-style questions, each addressing an aspect of student attitude toward chemistry class or attitude toward the intervention lessons (Appendix F). This questionnaire was based on items from the Science Motivation Questionnaire II, with modifications to suit this study (Glynn, Brickman, Armstrong, & Taasobshirazi, 2011). Four or five questions addressed each of the attitude and engagement categories *Interest/Enjoyment*, *Confidence/Achievement*, *Relevance/Importance*, and *Effort*. Six questions each were also asked about the use of history and pseudoscience intervention lessons. The scale for this instrument was assigned values with 1 indicating the lowest and 5 the highest level of interest or engagement. This questionnaire was administered after completion of the intervention lessons, and mean and median scores and frequencies

were calculated for all questions. Mean values were also calculated for each Likert scale question group and again the Wilcoxon Rank Sum test was applied to test for significance.

Structured interviews were administered near the end of the treatment period to 10 students representing a cross section of students involved in the study, using the Chemistry Attitudes Interview Questions (Appendix G). Interview data was used to provide additional valuable information regarding the students' understanding of the NOS and also attitudes towards the intervention lessons and studying chemistry in general.

Table 4
Data Triangulation Matrix

Research Question	Data Collection Instruments		
	1.	2.	3.
1. Does the use of pseudoscience and history of science case studies improve students' understanding of the nature of science?	Views About Science Questionnaire	Views About Science Open-Ended Questionnaire	NOS Misconception Probe – Pre NOS Misconception Probe – Post
2. Does use of HOS/PS case studies improve student engagement?	Chemistry Attitude Questionnaire	Structured Interviews (Chemistry Attitudes Interview Questions)	Observation in class
3. Does use of HOS/PS improve attitudes toward studying chemistry?	Chemistry Attitude Questionnaire	Structured Interviews (Chemistry Attitudes Interview Questions)	Observation in class

Interview responses were examined to find common themes and these themes were then categorized according to how favorable or unfavorable they were towards chemistry class, towards the intervention lessons and in terms of understanding of the NOS.

Finally, observation notes were kept in a teaching journal during the treatment period to record how students reacted to the intervention lessons. These observations were used to assist in answering the sub-questions regarding student engagement and attitudes.

DATA AND ANALYSIS

The results from the Views About Science Questionnaire indicated an improvement in student understanding of the Nature of Science (NOS), with 80% of the questions showing an increase and the overall mean score increasing by 7.6% ($N=51$). All of the data collection instruments were administered anonymously, and therefore scores for pre- and post-tests by individuals could not be compared. Instead the mean score for each question across all Views About Science Questionnaire pre-tests and post-tests was calculated for comparison.

Comparison of mean scores for individual questions revealed that a few of the questions in particular had larger pre- to post-test increases (Figure 1). For instance the question concerning the fallacy that scientific knowledge will gradually approach an absolute truth (Question 3), improved by nearly 22% from a mean of 2.08 to 2.53. Mean scores for the questions which dealt with the scientific meaning of *theory* and *law* (Questions 10, 11 and 12), improved by 21%, 11.6% and 32% respectively despite the fact that the scores remained quite low, in the range of 2.

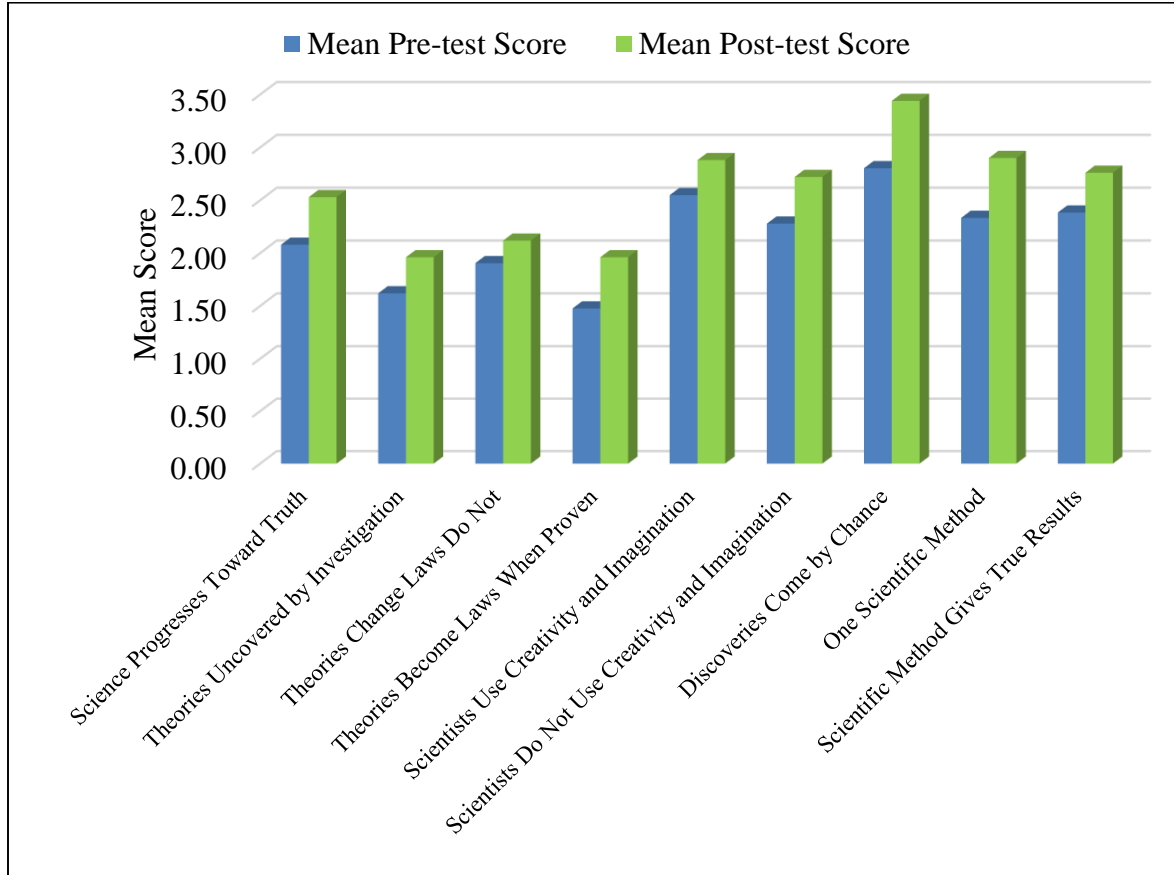


Figure 1. Views About Science Questionnaire scores for selected questions, ($N=51$). Scored on a four point scale with 1 representing lowest understanding of the NOS.

Similarly, the questions dealing with scientists making discoveries through creativity, imagination and luck (Questions 18, 19 and 20) exhibited gains of 13%, 19% and 22.8%. Finally, the questions about the misconception of a single scientific method (Questions 22 and 23) showed gains of 24.5% and 16%.

When only the six questions that had pre-test scores greater than 3.0 were examined, the data revealed very small differences between pre- and post-test mean scores (Figure 2).



Figure 2. Views About Science Questionnaire scores for questions with pre-test scores greater than 3.0, ($N=51$). Scored on a four point scale with 1 representing lowest understanding of the NOS.

The questions on the Views About Science Questionnaire fell into six groups, each consisting of four or five questions dealing with particular aspects of the NOS (Table 5).

Table 5
Likert Scale Question Groupings on Views About Science Questionnaire

Group	Aspects of NOS Addressed	Questions	Mean score, pre-test	Mean score, post-test
1.	1. Tentativeness	1-4	2.88	3.05
2.	7. Human Endeavor	5-8	2.86	2.98
3.	4. Models, Laws and Theories	9-13	2.17	2.35
4.	8. Culture and Society	14-17	2.70	2.83
5.	5. Creativity and Imagination 6. Logic, Consistency and Critical Thinking	18-20, 25	2.43	2.82
6.	2. Empirically Based 3. Methods	21-24	2.90	3.09

Analyzed as Likert scales, data from the Views About Science Questionnaire indicates that understanding of all aspects of the NOS improved (Figure 3). A Wilcoxon rank sum test revealed that the increase in mean scores was significant for four of the six categories ($p < 0.05$).

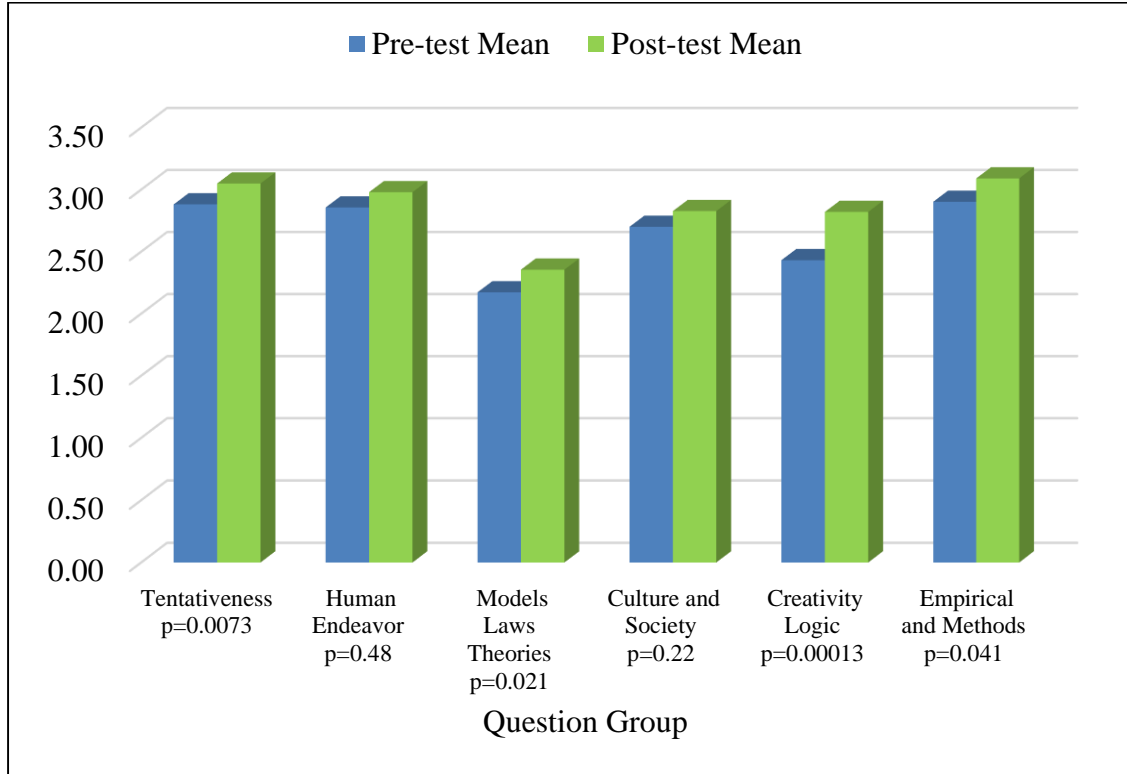


Figure 3. Pre- and post-test mean scores for question groups on the Views About Science Questionnaire, ($N=51$). Scored on a four point scale with 1 representing lowest understanding of the NOS.

When overall frequencies for pre- and post-test responses from all surveys were examined, the data revealed a shift towards better understanding of all aspects of the NOS. The frequencies of level 1 responses decreased from 15.9% in the pre-test to 10.2% in the post-test, while the level 4 responses showing greatest understanding increased from 23% to 29.7%. Level 2 responses also decreased slightly in frequency while level 3 responses increased slightly as well (Figure 4).

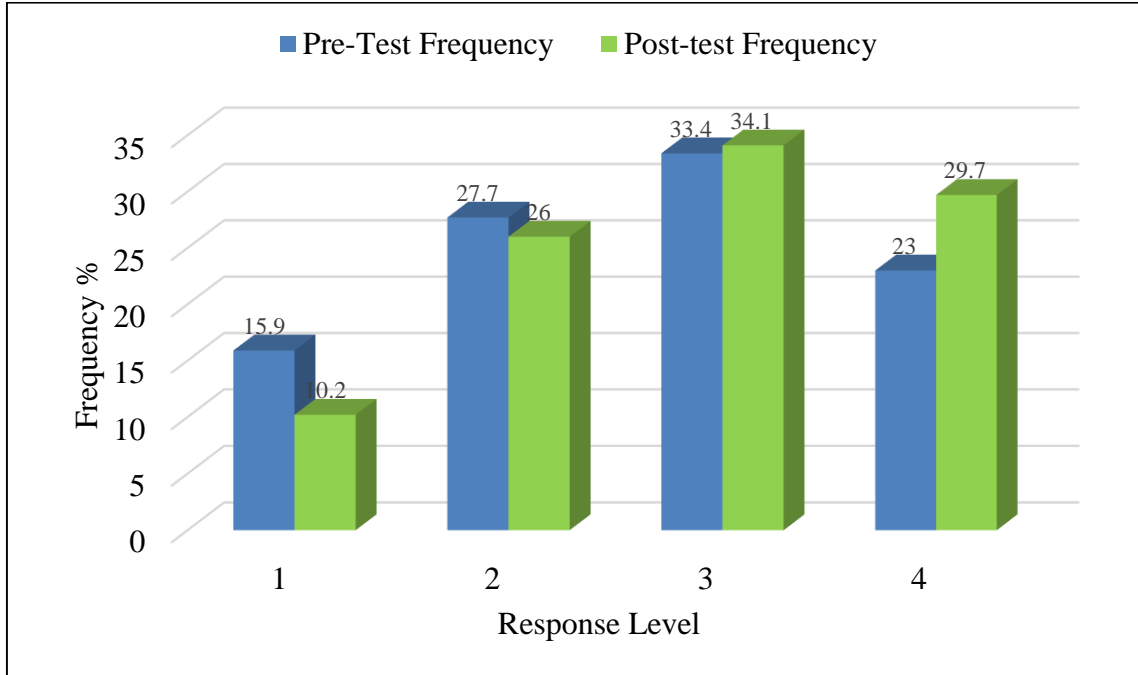


Figure 4. Frequencies of responses at each level on the Views About Science Questionnaire, ($N=51$). Scored on a four point scale with 1 representing lowest understanding of the NOS.

The Views About Science Open-Ended Questionnaire provided additional information on several aspects of the NOS and were scored on a 1-4 scale. Only one pre-test paper received a score of 1, indicating a very poor understanding of the NOS. The papers receiving a score of 2 typically had very basic answers and were not internally consistent. Students tended to believe that scientists follow a more rigid scientific method, and that data needed to be quantitative and always led to similar conclusions. Questionnaires receiving a score of 3 displayed understanding that data and evidence might be similar, and that scientists might have different experimental results, but generally because of experimental error or variations in the data they collected. They understood that scientists might use some different methods to investigate a problem but

still generally followed the same process. Their answers often provided more justification.

Students whose questionnaires scored 4 showed that they understood scientists do not follow one scientific method and that they may interpret data differently, because of biases or prior knowledge for instance. They generally explained better what data and evidence meant to them, and tended overall to more clearly justify responses (Table 6).

Table 6
Cross Section of Typical Responses for the Views About Science Open-Ended Questionnaire

<i>Question</i>	<i>Pre-test Response indicating lower understanding</i>	<i>Pre-test response indicating higher understanding</i>
If several scientists ask the same question and follow the same procedures to collect data, will they necessarily come to the same conclusions? Explain why or why not.	“Yes because they asked the same question and collected data in the procedures.”	“No, because data can be interpreted in different ways even with the same data.”
What does the word “data” mean in science? Is data the same or different than “evidence?”	“Data is like stats. It’s better. Evidence is weaker.”	“Data is what is collected from an experiment. Evidence could be any result found.”
	<i>Post-test response: lower understanding</i>	<i>Post-test response: higher understanding</i>
If several scientists ask the same question and follow the same procedures to collect data, will they necessarily come to the same conclusions? Explain why or why not.	“No, there could be different things that could contribute to error that would make the results different.”	“Not necessarily because personal bias, opinions and views will cause some conclusions to be different.”
What does the word “data” mean in science? Is data the same or different than “evidence?”	“I think they are different. Evidence proves it’s there. Data is just the stuff collected to start showing it’s there.”	“Data is the information given or found by experimenting. I would consider data and evidence to mean the same.”

Comparison of the pre- and post-test scores for this instrument indicated that the students’ understanding of the NOS had improved, with a pre-test mean score of 2.66

($N=56$) while the post-test mean was 2.92 ($N=50$). The responses themselves also provided qualitative evidence of a deeper grasp of the NOS concepts. A comparison of high and low-level responses from the pre-test and post-test illustrated that the post-test responses, whether showing a higher or lower level of NOS understanding were more complete and better justified in terms of the NOS.

For example, in answer to the first question which asked whether scientists following the same procedures and different procedures to investigate a question will come to the same conclusions, one student's post-test response although simply worded displayed a good understanding of the scientific process: "No, although the scientists follow the same steps, they have different ideas that they are thinking during and after the experiment...Scientists all have different ideas and obviously following different procedures could make their conclusions different from one another."

When frequencies for responses were examined, they also showed an increase in understanding between the pre-test and post-test (Figure 5). The number of questionnaires signifying a low level of understanding with a score of 2 decreased from 37.5% to 32% while at those indicating a very strong understanding of the NOS with a score of 4 increased from 3.6% to 24%. The pre-test data included more scores of 3, but there is a clear shift towards higher scores

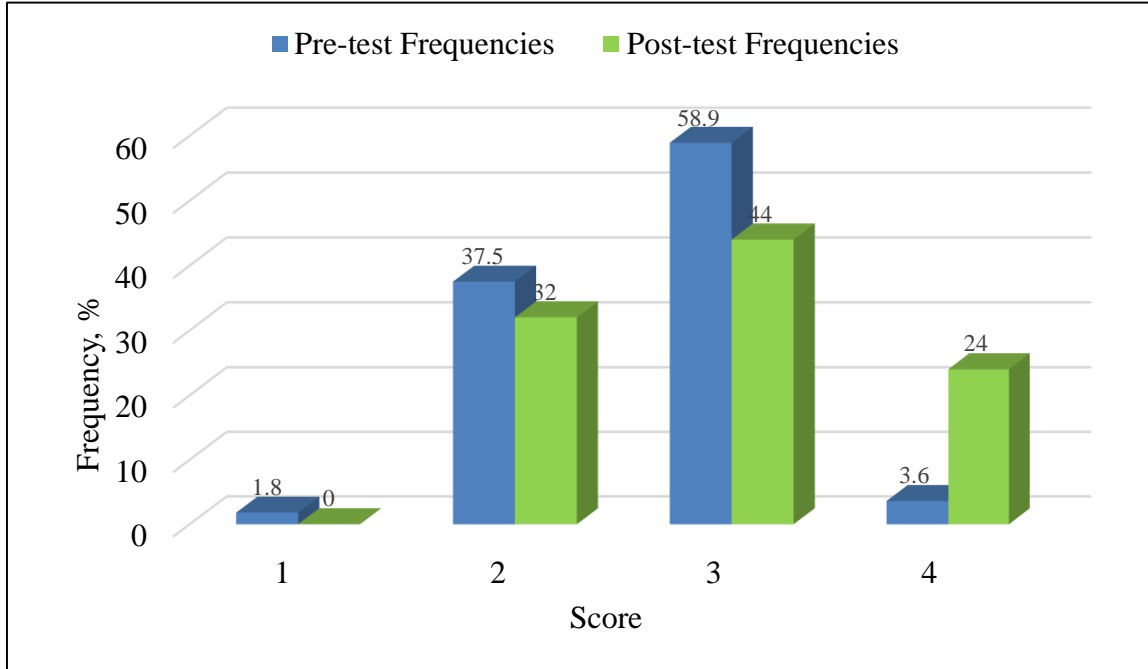


Figure 5. Frequencies of pre- and post-test scores for the Views About Science Open-Ended Questionnaire, ($N=50$). Scored on a four point scale with 1 representing lowest understanding of the NOS.

A comparison of boxplots of the pre-test and post-test scores provides further evidence that understanding improved (Figure 6). The notches in the boxplots show an increase in the median of the post-test scores, while the whiskers indicate that there is much less variation in the post-test responses as well.

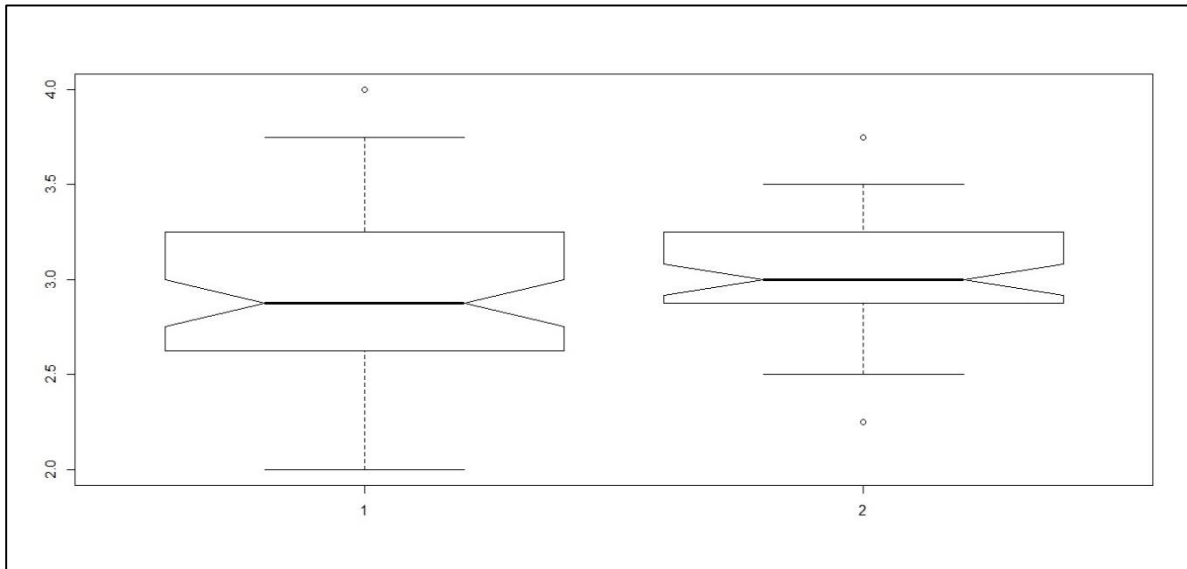


Figure 6. Boxplots of pre-test (1) and post-test (2) data for the Views About Science Open-Ended Questionnaire, ($N=50$). Notches indicate median; whiskers indicate interquartile range. Scored on a four point scale with 1 representing lowest understanding of the NOS.

The data for the Misconception Probe-(Pre) had a mean score of 2.74 ($N=52$) while the Misconception Probe-(Post) provided a mean score of 3.12 ($N=49$), indicating a gain in understanding of the NOS. A Wilcoxon Rank Sum test indicated the increase was significant ($p = 0.012$).

With the ordinal data provided by this instrument it was again appropriate to examine frequencies of scores (Figure 7). Frequencies indicated an increase in understanding as level 2 responses decreased by more than half from 44.4% to 18.4% of the papers while the responses scoring 3 increased from 35.2% to 49% and the level 4 responses increased from 18.5% to 30.6%.

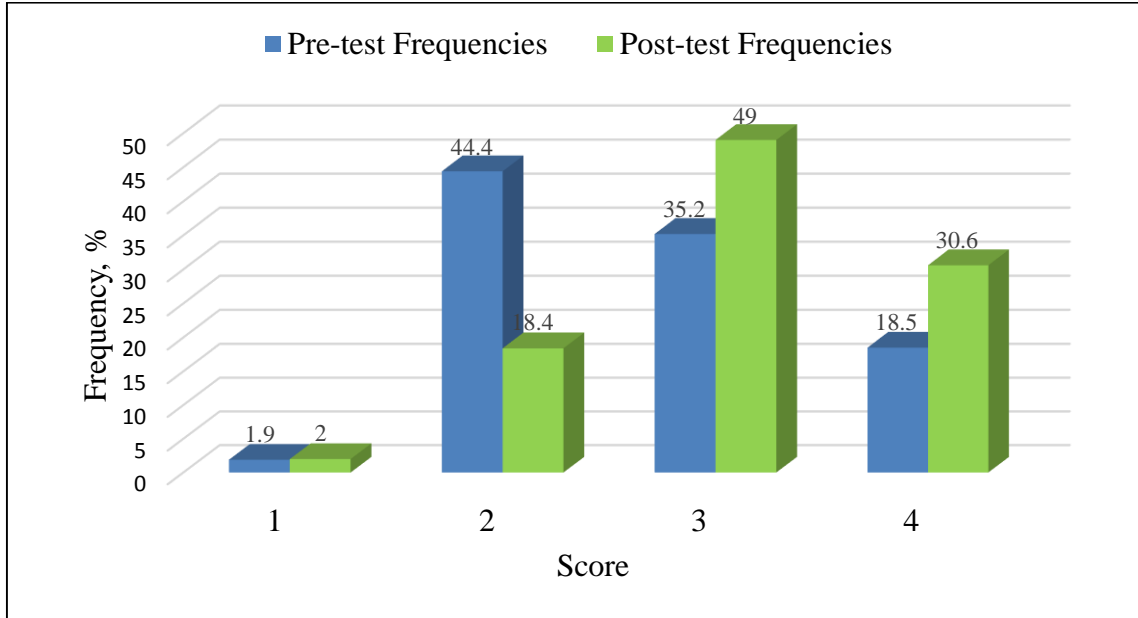


Figure 7. Frequencies of pre- and post-test scores for the Misconception Probes, ($N=49$). Scored on a four point scale with 1 representing lowest understanding of the NOS.

Boxplots of the Misconception Probe data also showed that there was a move toward greater understanding in the post-tests. The median was slightly higher but the bulk of the responses shifted higher (Figure 8).

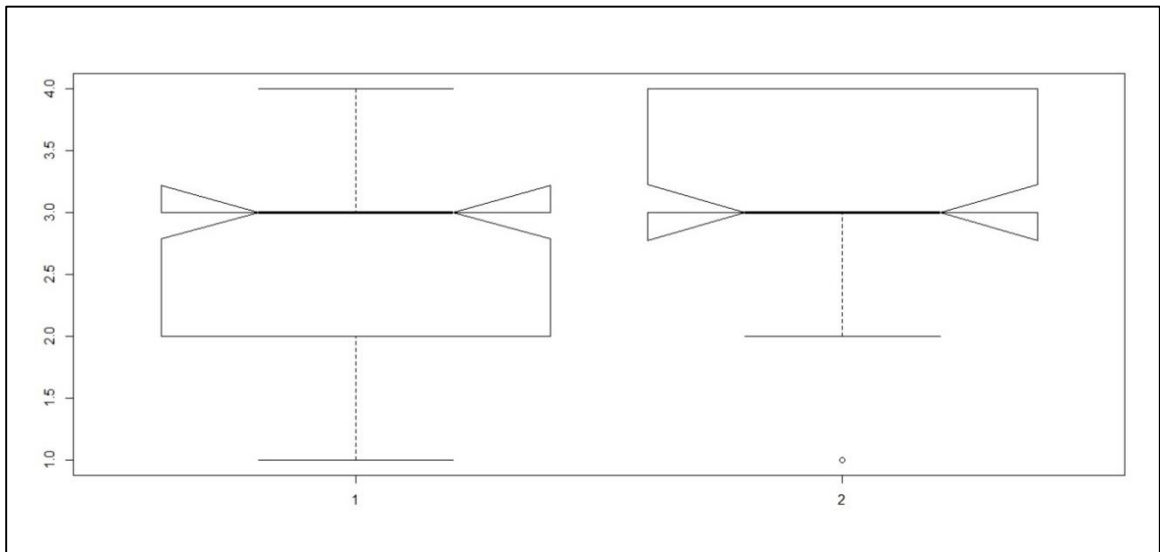


Figure 8. Boxplots of pre-test (1) and post-test (2) data for Misconception Probes, ($N=49$). Notches indicate median; whiskers indicate interquartile range. Scored on a four point scale with 1 representing lowest understanding of the NOS.

These instruments also provided qualitative data because they allowed for written responses. On the pre-test students often indicated they understood that scientific knowledge is tentative, with responses like “[I agree with] Steve, they say nothing is certain in science which is true because we are always discovering new things,” but did not often show a clear understanding of what laws and theories were. The most common statements said things like “Timmy is right because they might not be correct but if proven correct by others it becomes a law” or “I agree with Timmy because [theories] are not proven whereas laws are.” These statements all show a basic understanding of these aspects of the NOS.

Responses on the post-test much more frequently chose the best statement in the story, and provided justification that indicated a better understanding of the NOS. “[I agree with] Jimmy, scientists don’t really have a method they have to follow and a lot of experiments are discovered based on luck or accident” was typical of these answers. Another student received a score of 4 for the statement “...I feel that scientists investigate in many different ways, not just following one set method or procedure,” while “some things in science that are discovered by luck while investigating a different thing are much more useful” also showed that the student clearly understood that there is no set scientific method followed by all scientists. Both of these were quite typical of post-test responses, which were often more complete and generally indicated a better understanding than the pre-test.

All of the students interviewed felt that the intervention lessons taught them something about how science works. “Yes, for sure,” answered one student, “especially

the history lessons showed different ways people made discoveries. You don't learn that in other classes." Another answered "I didn't really think that our culture and society had anything to do with [science], but I found out that it's the basis for why things get done." A comment about the pseudoscience lessons indicated that they also helped show the NOS: "I see lots of that stuff on social media and I question whether it's legitimate. It gave me some idea about how to investigate them."

The Chemistry Attitudes Questionnaire was aimed at evaluating the two sub questions of this study – does the use of history and pseudoscience lessons improve student attitudes and engagement in chemistry class? The results from the Chemistry Attitudes Questionnaire showed very little difference between pre-test ($N=58$) and post-test scores ($N=52$). The overall mean score indicated a slight 1.6% decrease from 3.71 to 3.65.

The Chemistry Attitudes Questionnaire was a Likert-style questionnaire, and therefore the data can be more meaningfully analyzed by considering mean scores for each Likert scale grouping of questions. The questions were divided into six groups with four to six questions each (Table 7).

Table 7

Question groupings for Chemistry Attitudes Questionnaire.

Question group	Questions included
1. Interest and enjoyment of chemistry class	1, 12, 19, 23, 27
2. Confidence in abilities in chemistry and performance in chemistry class.	2, 9, 16, 17, 25
3. Enjoyment of pseudoscience lessons	3, 10, 13, 15, 20, 30
4. Importance of studying chemistry.	4, 6, 11, 22, 29
5. Enjoyment of history lessons.	5, 7, 18, 20, 24, 26
6. Effort in chemistry class.	8, 14, 21, 28

When the mean scores for the question groups were compared, the results showed very slight differences between pre- and post-test values, and the data was inconsistent. Wilcoxon Rank Sum test results revealed that none of the question groups showed significant change, with p-values between 0.052 and 0.76 (Figure 9).

In class observation provided more positive evidence of attitudes and engagement than the questionnaire data. Teacher journal entries regarding student reception of the intervention lessons indicate all of the pseudoscience lessons were well received by students, although some were more popular than others. The entry regarding the pseudoscience lesson on Q-Ray and Power Band bracelets, for example, states that “the students in all three classes really enjoyed this one. There was lots of discussion about the claims made and the lack of empirical evidence to support them. It is nice to see some discussion in the two quiet classes for a change!”

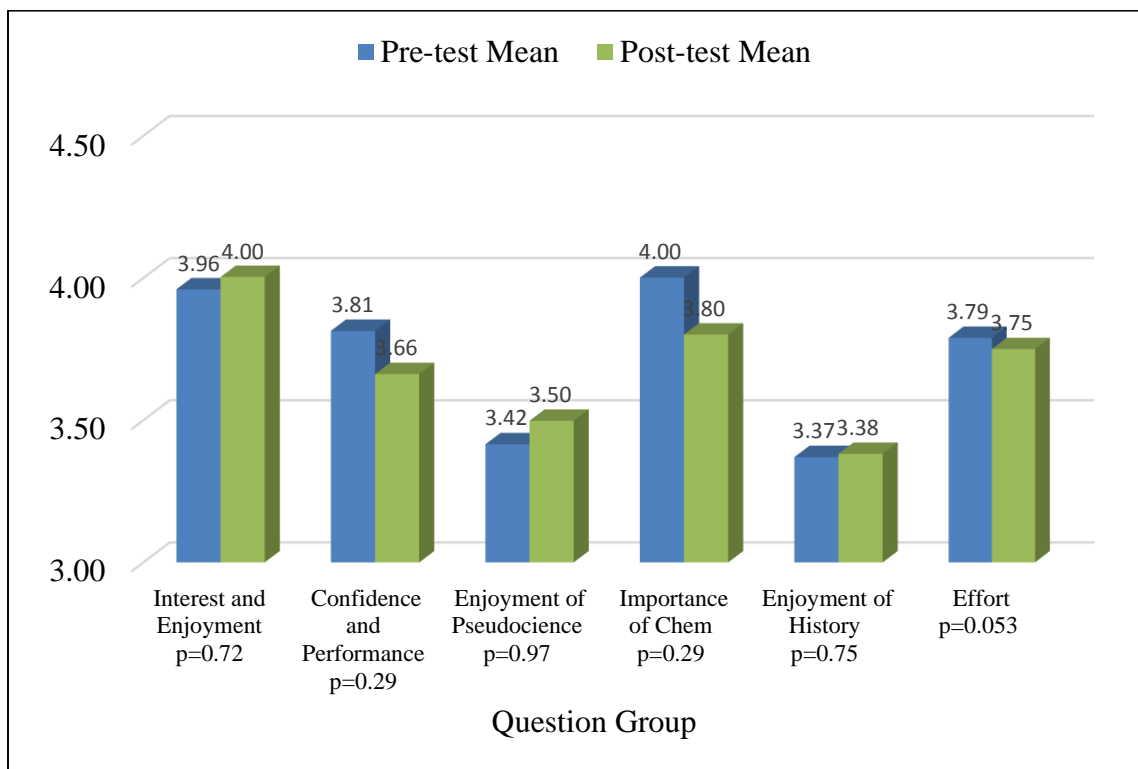


Figure 9. Pre- and post-test mean scores for question groups in the Chemistry Attitudes Questionnaire, ($N=52$). Scored on a five point scale, with 1 representing lowest level of interest and engagement.

Similarly, for the lesson on the anti-vaccine movement “they really loved the Penn and Teller video clip. There was a pretty clear consensus that all of the science supports vaccination. They really ‘got’ the idea of herd immunity.”

The lesson on the discovery of Buckyballs generated the comment “They liked that video quite a bit. It is generally well received by all the classes, but the grade 11 IB’s really enjoyed it this time. They found some of the parts funny, and they really wanted to finish it the next day after leaving off three-quarters of the way through. The video generated some discussion and questions afterward.”

While the lesson about the discovery of a variety of coal tar derivatives was probably the most popular history lesson with the entry “I think they enjoyed this one the

best, probably because of the humor in the presentation,” none of the journal entries indicate that any of the lessons was poorly received. The least enthusiastic entry is for the lesson on the creation of new elements. “They were a bit quieter about this lesson in all classes. It might have been a bit long, and I had to rush it a bit. I thought the part about academic misconduct would be more interesting, but [they said] nothing much.”

Structured interviews of a cross section of students provided a great deal of positive data. All of the students interviewed were very positive about the project, at least because the history and pseudoscience lessons were something different. “Yes those lessons were nice; they gave a bit of a break from the normal stuff,” was typical. Another said of the history lessons “Yes [I enjoyed those] very much. They gave a different perspective. They were interesting – learning the way stuff developed is cool.”

This sentiment that the history lessons were enjoyable and valuable was shared by most that were interviewed, with only one student expressing dislike for them. In the opinion of one “when you know where stuff came from it helps you understand it better. And I liked the stories.” Another felt “it helps tie in to other stuff. The history helps to connect things.”

Opinions were similarly positive about the pseudoscience lessons, with comments like “those were interesting. I liked learning about those topics.” “I liked those because some people believe in that stuff” said one grade 11 student. “I am naturally skeptical and I like to see that there’s proof. I read about that too.”

INTERPRETATION AND CONCLUSION

The results of this study supported the use of brief pseudoscience and history of science lessons as a useful vehicle for teaching the Nature of Science (NOS). Although the quantitative gains shown by the Views About Science Questionnaire were small, they did indicate a consistent improvement in understanding for all aspects of the NOS, greater in certain areas than in others. With the other data collection instruments taken into consideration more definitive conclusions could be drawn, and it became clear that students' overall understanding of the NOS had improved.

The data also pointed out that some areas of the NOS were already more familiar to my students than others. Those questions with the highest pre-test scores on the Views About Science Questionnaire showed no significant pre- to post-intervention change. These were the ideas that theories may be subject to revision and change in light of new evidence, that scientists may use different methods and that they may come to different conclusions from the same data. The Likert scale data for this instrument supported this conclusion as well.

The fact that some aspects were better known before the study began gave clear indication that teachers need to focus on some areas of the NOS more than others. The aspects that needed the most attention for my students were those dealing with models, laws and theories and the idea that scientists rely on creativity and imagination when solving problems. The misconceptions that scientists follow a rigid method and apply rules to come to definite conclusions, and that theories are somehow less well established than laws were obviously well ingrained in students' minds and therefore needed to be

addressed more vigorously than other aspects. This is emphasized by the fact that when asked directly about these aspects the students responded to indicate better understanding, but when these concepts were addressed in more subtle ways and embedded in other questions the responses were often contradictory.

For some aspects of the NOS the quantitative data suggested that understanding did not change a great deal. For example the ideas that scientists are subject to the same human biases and influences as the rest of us, and the role played by culture and society in science gave nearly the same scores pre- and post-intervention. Qualitative data, though, indicated that more subtle changes in understanding had occurred and that students had a much more clear and developed understanding of all aspects of the NOS after the intervention lessons.

A complicating factor in this study is that I have always actively taught NOS lessons in my classes, and that a significant portion of the students involved in this study would have taken part in some of those lessons. Nearly one third (approximately 15 students) of the study participants in my grade 12 class were in my grade 11 classes last year, and although they did not see any of the specific intervention lessons used for this study they would have had some history and pseudoscience lessons and some instruction in the NOS. This would have raised their pre-test scores to some degree, making it difficult to properly quantify the effects of this study. In this case the qualitative data again helped to clarify that gains in understanding had been made.

When considering the first sub-question, whether the intervention lessons improved student engagement, data from the Chemistry Attitudes Questionnaire indicated

a slight positive effect. Qualitative data from class observation and student interviews, however, indicated quite clearly that these lessons were well received and engaging to students. Although the pseudoscience lessons were more engaging for a few students than the history lessons, the history lessons generally addressed more aspects of the NOS more easily and directly than the pseudoscience lessons did, and often provided a better vehicle for teaching the NOS. History lessons were also seen by students to be beneficial in providing connections and context for curricular material. Pseudoscience lessons, on the other hand, provided useful exercises in critical thinking and skepticism.

The answer to the second sub-question, whether the intervention lessons improved student attitudes toward studying chemistry, was even less clear in the quantitative data. The Chemistry Attitudes Questionnaire question groups directed at this question showed no real change. Teaching journal entries and student interviews did not provide enough additional data to be able to draw a definite conclusion.

VALUE

This project was very important for me because it allowed me to investigate systematically and attempt to quantify some of the things I have been doing in my teaching for quite some time. I have always used examples of pseudoscience with my classes, often to point out the errors in scientific reasoning they illustrated or the lack of empirical evidence to support them. I have also been incorporating stories from the history of chemistry into lessons for several years. I had always felt my students enjoyed these history and pseudoscience lessons as much as I did but I had no data to support that.

I also believed that these stories could help provide some context for my students' chemistry studies. This study has proven me correct on both counts.

This research has shown that the lessons I developed in pseudoscience and history are interesting to students and the data indicated that they are definitely effective for teaching the Nature of Science. Doing this study allowed me to more formally develop many lessons which I will continue to use in my classes. More importantly doing this project forced me to really take apart and examine the NOS in the context of how to teach it to students, and that by itself made my NOS teaching more effective. The primary consideration was always benefit to the students, and participating in this study helped my students by improving their understanding of how science and scientists worked. It also improved their critical thinking and skepticism, providing them with some tools for examining questionable claims. My future students will definitely benefit as well.

This project reminded me of the importance of teaching what "science" really is. Citizens of today's science and technology-rich society need an understanding of the process of science and an ability to think critically. It has become clear that the intervention methodology of this study provided science teachers with an effective model for delivery of lessons to address the NOS. The use of brief anecdotal lessons from history and pseudoscience improved student understanding of the NOS without requiring a great deal of additional time or resources outside of the regular curriculum. In fact, the intervention lessons generally fit well with curricular material and provided reinforcement for those ideas as well. At the same time these lessons improved student engagement and interest in chemistry.

The data also made it clear that student misconceptions about the NOS, particularly the myth of the Scientific Method and the meanings of law and theory were well entrenched. These aspects in particular need to be focused on by teachers and I will continue to develop materials to address this in my classroom.

I feel that undertaking this action research process has benefitted me as a teacher as well. At this advanced stage of my career, the tendency is to feel that there is nothing new to be learned, and that one has seen it all. Instead I felt like I have tried some things that I hadn't before, and that I definitely learned some new things along the way.

This project has taught me the value of qualitative data. As a chemistry teacher I tended to think quantitatively most of the time, but this research showed me how powerful and informative qualitative data can be. If I had to rely solely on the more quantitative instruments my research would have been quite inconclusive. The qualitative instruments were invaluable in providing data to support conclusions.

Finally, I have been reminded of the value of reflection as part of the teaching process. Too often we get caught up in the busy day-to-day grind and forget to take the time to dissect what we are doing and think carefully about how we can best help our students learn. At first the reflection was forced, as part of the research process. As it progressed I came to realize the benefit of reflection for me and for my students as well. It allowed me to think about what I had been doing and how to modify lessons and materials based on data from students. As a result of this process I became a better teacher, and my students benefitted because of it. For me, that was the most valuable outcome.

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APPENDICES

APPENDIX A

NATURE OF SCIENCE INTERVENTION LESSONS

History of Science
Intervention Lessons:

<u>Topic</u>	<u>Lesson Format</u>	<u>Aspects of NOS Addressed</u>
1. Priestley and the Discovery of Oxygen	ACS lesson – Readings and Discussion	All aspects (Used to introduce the NOS).
2. What Can You Do With Coal Tar? (Saccharin and Mauve)	Prezi Presentation	Empirically-based; Models, Laws and Theories; Creativity and Imagination.
3. The Manhattan Project and Creation of New Elements	PowerPoint presentation	Culture and Society; Human Endeavor; Models, Laws and Theories.
4. The Model of the Atom (Grade 11)	Lecture and video	Models, Laws and Theories; Tentativeness; Creativity and Imagination; Empirically based
Discovery of Fullerenes (Grade 12)	Video and Discussion	
5. From Radar to Radarange (Microwaves)	Prezi presentation	Creativity and Imagination; Empirically based; Culture and Society.
6. Thomas Midgeley (Tetraethyl Lead and CFC's)	Prezi presentation	Culture and Society; Logic, Consistency and Critical Thinking; Creativity and Imagination

Pseudoscience Intervention
Lessons:

<u>Topic</u>	<u>Lesson Format</u>	<u>Aspects of NOS Addressed</u>
1. Homeopathy	PowerPoint presentation and video clip	Empirically-Based; Logic, Consistency and Critical Thinking
2. Astrology and Horoscopes	Prezi presentation and activity	Empirically-Based; Logic, Consistency and Critical Thinking; Culture and Society; Tentativeness.
3. PowerBands and Q-Ray Bracelets	Review of promotional material and discussion.	Empirically-Based; Logic, Consistency and Critical Thinking
4. Reiki and Therapeutic Touch	PowerPoint presentation and video clip	Empirically-Based; Logic, Consistency and Critical Thinking; Culture and Society.
5. Dowsing	Demonstration and video clip	Empirically-Based; Logic, Consistency and Critical Thinking; Human Endeavor.
6. The Anti-vaccine movement	PowerPoint presentation, video clip and discussion	Empirically-Based; Logic, Consistency and Critical Thinking; Culture and Society

APPENDIX B
VIEWS ABOUT SCIENCE QUESTIONNAIRE

Views About Science Questionnaire

Participation in this research is voluntary. Participation or non-participation will not affect your grades or class standing in any way.

For each of the following statements about science, indicate whether you

Agree (A)

Agree somewhat (AS)

Disagree somewhat (DS)

Disagree (D)

Please **circle** your choice.

- | | | | | | |
|-----|---|----------|-----------|-----------|----------|
| 1. | Scientific theories are subject to ongoing testing and revision. | A | AS | DS | D |
| 2. | Scientific theories may be completely replaced by new theories in light of new evidence. | A | AS | DS | D |
| 3. | As scientific knowledge develops it will approach the absolute truth. | A | AS | DS | D |
| 4. | We accept an idea as scientific knowledge only if it does not have any error. | A | AS | DS | D |
| 5. | Science knowledge is based on evidence. Scientists should not have personal opinions. | A | AS | DS | D |
| 6. | Scientists' observations of the same event will always be the same because scientists are completely objective. | A | AS | DS | D |
| 7. | Scientists' observations of the same event will always be the same because observations are facts. | A | AS | DS | D |
| 8. | Scientists may make different interpretations based on the same observations. | A | AS | DS | D |
| 9. | Scientific theories based on accurate experimentation will not be changed. | A | AS | DS | D |
| 10. | Scientific theories exist in the natural world and are uncovered through scientific investigations. | A | AS | DS | D |
| 11. | Theories may change but laws do not changes. | A | AS | DS | D |

- | | | | | |
|--|---|----|----|---|
| 12. Scientific laws are theories that have been proven. | A | AS | DS | D |
| 13. Scientific theories explain scientific laws. | A | AS | DS | D |
| 14. Scientific research is not influenced by society and culture because scientists are trained to do “pure” unbiased research. | A | AS | DS | D |
| 15. Cultural values and expectations determine <u>how</u> science is conducted and accepted. | A | AS | DS | D |
| 16. Cultural values and expectations determine <u>what</u> research is done by scientists. | A | AS | DS | D |
| 17. All cultures conduct scientific research the same way because science is independent of society and culture. | A | AS | DS | D |
| 18. Scientists use their imagination and creativity when they analyze and interpret data | A | AS | DS | D |
| 19. Scientists do not use their imagination and creativity because these interfere with their logical reasoning and objectivity. | A | AS | DS | D |
| 20. Scientists often make discoveries by chance or luck. | A | AS | DS | D |
| 21. Scientists use a variety of different methods to conduct investigations. | A | AS | DS | D |
| 22. Scientists follow the same step-by-step scientific method. | A | AS | DS | D |
| 23. When scientists use the scientific method correctly their results are true and accurate. | A | AS | DS | D |
| 24. Experiments are not the only way that scientific knowledge can be developed. | A | AS | DS | D |
| 25. When scientists explain the results of an experiment they have to convince other scientists to agree with them. | A | AS | DS | D |

APPENDIX C

NOS MISCONCEPTION PROBE (PRE)

The Scientific Method?

One day while doing chemistry homework, *Jimmy* found the story of how the first artificial sweetener was created from coal tar. He said to his friends "It's interesting how lots of things are discovered completely by accident when the scientist is working on something completely different.

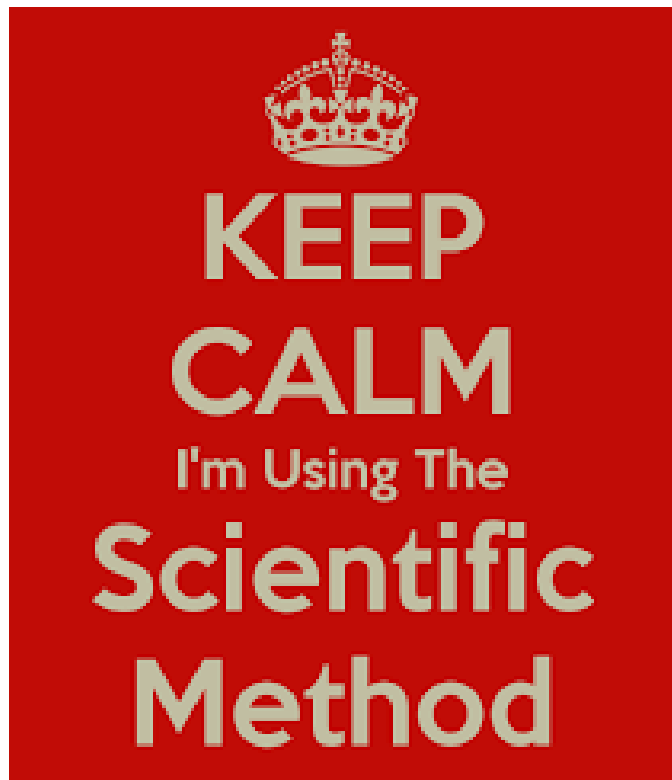
There is no scientific method, scientists investigate things lots of ways." Timmy replied "No, that's not true. Scientists all follow the same step-by-step scientific method to discover things and solve problems. That way it's always consistent and reliable"

Steve replied "I don't know about that. Scientists all have to follow the same scientific method, but I

think different scientists make different discoveries even when they're investigating the same thing. That's because they all would have their own ideas about things."

Do you agree most with Jimmy, Timmy or Steve? Explain why you agree with him.

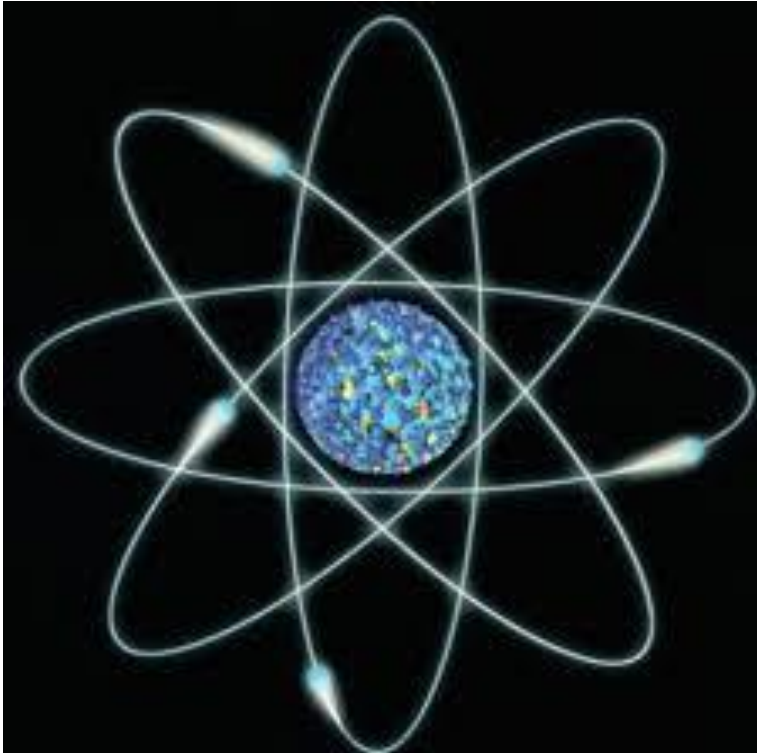
(Participation in this research is voluntary. Participation or non-participation will not affect your grades or class standing in any way.)



APPENDIX D

NOS MISCONCEPTION PROBE (POST)

The Theory Hypothesis



Jimmy, Timmy and Steve were in chemistry class one day and in between all the boring babble they heard Mr. Pfeifer mention something about Quantum Theory to explain how atoms work, and it sounded pretty complicated!

Jimmy said "Why do we need to learn this stuff anyway? If

it's a theory that means it's just somebody's guess, so it's probably wrong anyway.

"You're not exactly right," said **Timmy**. "A theory is something that people think might be correct, it's just not proven yet. If it's proven for sure it becomes a law.

"You're both wrong," answered **Steve**. "A theory is something that is supported by all the evidence scientists have. It's not certain because nothing's certain in science." A large fight ensued.

With whom do you **most agree** about what a scientific theory is? Why do you agree with him?

(Participation in this research is voluntary. Participation or non-participation will not affect your grades or class standing in any way.)

APPENDIX E

VIEWS ABOUT SCIENCE OPEN-ENDED QUESTIONNAIRE

Views About Science Open-Ended Questionnaire

Participation in this research is voluntary. Participation or non-participation will not affect your grades or class standing in any way.

1. a. If several scientists ask the same question and follow the same procedures to collect data, will they necessarily come to the same conclusions? Explain why or why not.

b. If several scientists ask the same question and follow different procedures to collect data, will they necessarily come to the same conclusions? Explain why or why not.

2. Two students are asked if scientific investigations must always begin with a scientific question. One student says “yes” while the other says “no.” Whom do you agree with and why?

3. What does the word “data” mean in science? Is data the same as or different than “evidence”?

4. A person interested in birds looked at hundreds of different types of birds who eat different types of food. She noticed that birds who eat similar types of food tended to have similar beak shapes. For example, birds who eat hard shelled nuts have short beaks, and birds that eat insects from tide pools have long, slim beaks. She made the conclusion that there is a relationship between the type of food birds eat and beak shape.

a. Do you consider this person's investigation to be scientific? Why or why not?

b. Do you consider this person's investigation to be an experiment? Why or why not?

c. Do scientific investigations follow the same method or can they follow different methods?

5. Two teams of scientists are walking to their lab one day and they saw a car pulled over with a flat tire. They all asked "Are some brands of tires more likely to get a flat than others?"

- Team A went back to the lab and tested various tires' performance on three types of road surfaces.

- Team B went back to the lab and tested one tire brand on three types of road surfaces.

Explain why one team's procedure is better than the other's

APPENDIX F
CHEMISTRY ATTITUDES QUESTIONNAIRE

Chemistry Attitudes Questionnaire

Participation in this research is voluntary. Participation or non-participation will not affect your grades or class standing in any way.

In order to better understand what you think and how you feel about your science and chemistry classes, please respond to each of the following statements in terms how often or to what degree they apply:

Never (N)

Rarely (R)

Sometimes (S)

Usually (U)

Always (A)

- | | | | | | | |
|-----|---|---|---|---|---|---|
| 1. | Learning chemistry is interesting. | N | R | S | U | A |
| 2. | I like to do better than other students on chemistry tests. | N | R | S | U | A |
| 3. | It is important to be skeptical about unusual claims. | N | R | S | U | A |
| 4. | Getting a good chemistry grade is important to me. | N | R | S | U | A |
| 5. | Learning about the history of chemistry helps me understand science better. | N | R | S | U | A |
| 6. | Learning chemistry will help me in my future studies. | N | R | S | U | A |
| 7. | I enjoy learning about the history of chemistry. | N | R | S | U | A |
| 8. | I put less effort into chemistry than other classes. | N | R | S | U | A |
| 9. | I am confident I will do well on chemistry tests. | N | R | S | U | A |
| 10. | Learning about pseudoscience is important | N | R | S | U | A |
| 11. | Knowing chemistry will give me a career advantage. | N | R | S | U | A |
| 12. | I do not like chemistry class | N | R | S | U | A |

13.	I am interested in learning about pseudoscience and skeptical thinking.	N	R	S	U	A
14.	I put enough effort into learning chemistry	N	R	S	U	A
15.	Learning about pseudoscience topics makes chemistry class more interesting.	N	R	S	U	A
16.	I believe I can master chemistry knowledge and skills.	N	R	S	U	A
17.	I pay attention in chemistry class.	N	R	S	U	A
18.	I am curious about how discoveries have been made in chemistry.	N	R	S	U	A
19.	I do not find chemistry class interesting.	N	R	S	U	A
20.	Learning about history and pseudoscience makes chemistry class more relevant.	N	R	S	U	A
21.	I study hard to learn chemistry.	N	R	S	U	A
22.	My career will involve chemistry or science.	N	R	S	U	A
23.	I enjoy chemistry class.	N	R	S	U	A
24.	Stories about the history of chemistry make chemistry class more interesting.	N	R	S	U	A
25.	I am confident I will do well on chemistry labs and projects.	N	R	S	U	A
26.	Learning about the history of chemistry is boring.	N	R	S	U	A
27.	I enjoy chemistry class more than other subjects.	N	R	S	U	A
28.	I spend a lot of time learning chemistry.	N	R	S	U	A
29.	Learning chemistry is important.	N	R	S	U	A
30.	Learning about pseudoscience makes me understand science better.	N	R	S	U	A

APPENDIX G

CHEMISTRY ATTITUDES INTERVIEW QUESTIONS

Remember that participation in this research is voluntary. Participation or non-participation will not affect your grades or class standing in any way.

1. What do you enjoy most about chemistry class? Explain.
2. What do you enjoy least about chemistry class? Explain.
3. Do you feel like you work hard to do all that you need to do for chemistry class? Explain.
4. Do you enjoy learning about topics about the history of chemistry? Why (not)?
5. Do you enjoy learning about pseudoscience topics in chemistry class? Why (not)?
6. Do you feel that these special topic lessons have added something positive to chemistry classes, or have they been a negative aspect of classes? Explain.
7. Do you feel that these special topic lessons have taught you something about how science works? Explain.
8. Is there anything else you would like me to be aware of?

APPENDIX H
INSTITUTIONAL REVIEW BOARD EXEMPTION



INSTITUTIONAL REVIEW BOARD
For the Protection of Human Subjects
FWA 00000165

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MEMORANDUM

TO: Ronald (Mark) Pfeifer and John Graves
FROM: Mark Quinn, Chair *Mark Quinn cy*
DATE: December 1, 2014
RE: "Teaching the Nature of Science Through History and Pseudoscience" [RMP120114-EX]

The above research, described in your submission of December 1, 2014, is exempt from the requirement of review by the Institutional Review Board in accordance with the Code of Federal regulations, Part 46, section 101. The specific paragraph which applies to your research is:

- (b) (1) Research conducted in established or commonly accepted educational settings, involving normal educational practices such as (i) research on regular and special education instructional strategies, or (ii) research on the effectiveness of or the comparison among instructional techniques, curricula, or classroom management methods.
- (b) (2) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified, directly or through identifiers linked to the subjects; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.
- (b) (3) Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures, or observation of public behavior that is not exempt under paragraph (b)(2) of this section, if: (i) the human subjects are elected or appointed public officials or candidates for public office; or (ii) federal statute(s) without exception that the confidentiality of the personally identifiable information will be maintained throughout the research and thereafter.
- (b) (4) Research involving the collection or study of existing data, documents, records, pathological specimens, or diagnostic specimens, if these sources are publicly available, or if the information is recorded by the investigator in such a manner that the subjects cannot be identified, directly or through identifiers linked to the subjects.
- (b) (5) Research and demonstration projects, which are conducted by or subject to the approval of department or agency heads, and which are designed to study, evaluate, or otherwise examine: (i) public benefit or service programs; (ii) procedures for obtaining benefits or services under those programs; (iii) possible changes in or alternatives to those programs or procedures; or (iv) possible changes in methods or levels of payment for benefits or services under those programs.
- (b) (6) Taste and food quality evaluation and consumer acceptance studies, (i) if wholesome foods without additives are consumed, or (ii) if a food is consumed that contains a food ingredient at or below the level and for a use found to be safe, or agricultural chemical or environmental contaminant at or below the level found to be safe, by the FDA, or approved by the EPA, or the Food Safety and Inspection Service of the USDA.

Although review by the Institutional Review Board is not required for the above research, the Committee will be glad to review it. If you wish a review and committee approval, please submit 3 copies of the usual application form and it will be processed by expedited review.