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Nature of Science and Minnesota Chemistry Education

Eric P. Yanke
St. Cloud State University, eyanke@sjprep.net

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by

Eric P. Yanke

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Thesis Committee:

Rebecca Krystyniak, Chairperson

Melissa Hanzsek-Brill

Mark Minger

Abstract

Minnesota chemistry teachers were surveyed to determine their practices for including nature of science content into general chemistry curriculum. Teacher experience, engagement in professional development and licensing institutions were compared with their tendency to include nature of science topics as part of their curriculum. Engagement in professional development was found to have the strongest relationship with a weak positive correlation. Participants also reported the specific nature of science standards they include in the instruction of general chemistry and the frequency of these responses are analyzed.

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INTRODUCTION

Introduction

The principles governing science education in Minnesota contain thirty standards addressing the nature of science and engineering for grades 9-12. However, there is no prescribed method for which high school science courses address each of the thirty standards. Focusing on the nature of science standards, this study is designed to investigate which of these standards are being taught in high school general chemistry classrooms in Minnesota schools. An online survey will be distributed to licensed high school chemistry teachers in the state of Minnesota. Data will be collected regarding personal teaching experience including years of teaching experience, school, and information about the teacher preparation program they completed. Further data will be collected on instructional practice regarding nature of science topics, the nature of science standards addressed within their classrooms, and pedagogical methods used to address these standards. These data will provide information on if and how high school chemistry teachers are including nature of science topics in the curriculum of their general chemistry classes.

Conceptual Framework

A goal of science education programs is to help develop citizens who are not afraid to engage in scientific thought and debate (Tytler & Symington, 2006). Tytler found that unnecessarily difficult and decontextualized science content tends not to develop students who are scientifically curious and literate (Tytler 2007). It is instead the study of nature of science topics that lead students to think scientifically and dispel common misunderstandings in science (Schwartz, Lederman & Abd-El-Khalick, 2012). The study of nature of science leads to citizens who can make informed decisions on topical issues in science, and the world, leading to scientifically literate citizens (Karakas, 2010). Previous research on nature of science will be used to guide the development and deployment of the research instrument. A literature review will provide definitions, a list of possible methods for the instruction of nature of science and a foundation for describing why nature of science topics are valuable in science education. The specific standards investigated will come from the Minnesota state science standards. Six standards that lend themselves to completion within a general chemistry classroom will be researched. The data will be analyzed within the context of the research questions.

Statement of the Problem

According to the Minnesota state science standards, it is clear there is an expectation that students are mastering nature of science content. The issue is that there is currently no way to determine which of these standards are being addressed in chemistry classrooms. The 10^{th} grade mastery test that all public high school students take to demonstrate mastery in science contains questions based on the standards from the strand of outcomes selected for this study. The only data reported from this test groups each of the sub-strands into one data point which simply shows an average score for the entire nature of science and engineering sub-strand (Minnesota Department of Education, 2015b). While raw data scores for student output are available, it is unclear what methods are being used by teachers to instruct students on nature of science topics.

This study will survey high school chemistry teachers in Minnesota to collect data on these two topics.

Purpose of the Study

The data collected in the online survey will be analyzed in two different ways. The frequency of selections to the standards addressed will be tabulated to determine which standards are most, and least, commonly covered in a high school general chemistry course. Secondly, relationships will be investigated among the number of years of experience for a chemistry instructor and the pedagogical methods selected for use in their classroom. Finally, relationships between the institution that recommended a candidate for licensure and the pedagogical methods used for instructing nature of science topics will be identified. This data will give a snapshot of how survey participants are integrating the nature of science standards into their curriculum. Beyond simply reporting the frequency of observed standards, the correlation between years of experience and teacher training programs with pedagogical methods used will inform possible opportunities for professional development. The data will also identify the rate at which different nature of science objectives are being addressed for teachers from different teacher preparation programs.

Assumptions of the Study

- Survey respondents will answer the survey questions in a truthful manner.
- Survey respondents will be a representative sample of Minnesota chemistry instructors.

- Survey respondents will be able to select both methods used and standards addressed without information from the survey biasing their understandings, definitions, or classifications of methods and standards.
- Each high school in Minnesota plans for, and meets, each of the standards outlined in the state science standards.
- The six standards selected from the nature of science strand represent standards that can be addressed within the context of a first year high school general chemistry course.

Delimitations

- The population surveyed in this study will consist of chemistry teachers with public school experience. Public schools are required by law to follow the outlined standards.
- The collection of demographic information will be limited to years of experience teaching chemistry, the types of degrees earned by the survey respondent, and date of initial licensure. The demographic information collected is limited to assist in anonymity. There is no information collected regarding personal identity and the responses to the survey are not linked to email addresses or personal contact information.
- A qualified participant for the survey is an instructor who is either currently teaching a high school general chemistry course or has taught a general chemistry course in the last three academic years. This will ensure that survey participants are sharing information regarding current practices.

- Only six standards were selected from the Minnesota state science standards, specifically the nature of science strand. These six standards were selected for their relevance to a general chemistry class at the high school level.
- Data is being collected on both the number of years of experience a chemistry teacher has accrued as well as date of initial licensure. This research is investigating the relationship between the number of years of experience of teaching chemistry and how it relates to selection of pedagogical methods. Date of initial licensure will also provide information on the era a teacher received training in pedagogical methods. The correlation between date of licensure and pedagogical methods can be examined so as to compare with the previously described relationship.

Research Questions

- What effects do teaching experience, teacher preparation, and in-service professional development have on chemistry teacher practice regarding nature of science?
- Which of the nature of science standards in this survey do Minnesota chemistry teachers most frequently address, and how are they included in their classes?

Definition of Terms

Nature of Science:

Science and nature of science are distinctly different, though often confused. A useful, yet imperfect, analogy is to think of nature of science as rules for science. They exist to guide science in a meaningful way without preventing growth and progress (Clough, 2000). There is not one explicitly defined and universally accepted definition for nature of science. The academic community approaches the task of defining NOS across a relatively broad range, from a general sense: as scientific epistemology, science as a way of knowing, and justification for the generation of new knowledge (Lederman, Lederman, & Antink, 2013), to: the process of breaking NOS science into its component parts (Lederman, N.G., 1992). Even when one of the previous approaches is favored in academic writing, both are typically present in some way. The general definition represents a big picture, high level, understanding of nature of science, where the latter manner of defining NOS represents a microanalysis of individual components. Though nature of science does not have an absolute definition, there are several components that appear repeatedly across current literature. A general agreement exists that the epistemology of science relies on six components of nature of science as well as two other relationships.

Scientific knowledge is:

- **Tentative** - subject to change based on new data, reinterpretation of existing data, or the presentation of improved explanations

- **Subjective** - scientific knowledge is founded in and supported by theories
- **Empirically Based** - observations of the natural world lead to the generation of scientific knowledge
- **Involves Human Bias and Interference** - even with the goal of maintaining absolute objectivity scientists will introduce subjective bias into their work, based on prior experience, research, and personal perspective
- **Creative** - aspects during the process of producing scientific knowledge require creativity from the design of experimental processes to the interpretation of data collected
- **Socially and Culturally Influenced** - scientists are influenced by the needs, values, and prior knowledge of their societies and cultures

(Akerson, Abd-El-Khalick, and Lederman, N., 2000; Karakas, 2011; Lederman, Lederman, & Antink, 2013).

Beyond these six facets of scientific knowledge, there are two other relationships that are relevant when defining, explaining, and discussing nature of science. The relationship between laws, theories, and hypothesis as well as the relationship between observations and inferences are worth differentiation. The terms law, theory and hypothesis are often misused and misunderstood. Lederman, Abd-El-Khalick, Bell, and Schwartz (2002) found that students often inappropriately hold the view that theories and laws have a hierarchical relationship. They are different types of scientific knowledge. Laws describe observable phenomena, whereas theories explain why an observable behavior exists (Lederman, Abd-El-Khalick, et al., 2002). Finally, there is a clear distinction between observations and inferences. Observations consist of recordable, qualitative, and quantitative findings, and inferences are deduced from a set of observations (Akerson, et al., 2000; Karakas, 2011; Lederman, Lederman, & Antink, 2013). This is a generally accepted definition used by scholars, historians of science, and philosophers of science. Though it is not universally accepted, it will guide the understanding of nature of science as referenced in this research.

Summary

The purpose of this research is to address a gap in the current literature regarding the practice of Minnesota chemistry teachers and implementation of nature of science standards in general chemistry classes. Quantitative data will be collected through an anonymous online survey. The survey will collect data regarding the practices of chemistry instructors and nature of science topics. Surveys will be distributed electronically to licensed chemistry teachers in the state of Minnesota. The data will include the topic/standards addressed as well as the methods used for instruction. Ultimately, this information can be a guide for future professional development opportunities and the identification of opportunities for improvement in teacher preparation programs.

CHAPTER 2

LITERATURE REVIEW

Introduction

The purpose of this study is to collect data on which nature of science (NOS) topics Minnesota chemistry teachers address in their classrooms and the methods used to help students learn nature of science content.

- NOS Justification and Benefits: A historical analysis of how and why nature of science topics are included in science education will be assembled. This overview will include multiple cultural perspectives and a review of the past century of educational research regarding NOS , including justification and reasons for including nature of science content as a valuable part of science curriculum. Benefits from engaging in nature of science content to students, classrooms, communities, and society will also be noted in this section.
- Teacher Experience: Research outlining the experience and practice of novice teachers, those with fewer than five years of experience, regarding the instruction of nature of science will be examined.
- Pedagogical Methods: Research on current pedagogical approaches used in the field of science education, specifically for the instruction of nature of science. Data suggesting the relative value of different methods will also be considered.

Review of the Research on Issues Relevant to the Study

NOS Outcomes in Education

Learning outcomes reflecting an understanding of the nature of science (NOS) have been common to science curriculum for over one hundred years. There are documents from as early as 1907, in which the Central Association of Science and Mathematics Teachers argue for the emphasis of scientific process in the curriculum as opposed to science content being the sole focus of science education (Lederman, N.G., 1992). The tendency to value NOS as part of an educational curriculum is not unique to the United States. Much of the research regarding NOS and elementary/secondary schools has been done across the world, including countries such as Turkey, Australia, and Israel (Cil & Cepni, 2012; Karakas, 2011; Tytler, 2007). Nature of science refers to science as a way of generating knowledge. The National Science Teacher's Association describes NOS through several premises. They include statements about scientific knowledge as simultaneously reliable and tentative; scientific methods; creativity and subjectivity; and the generation of knowledge in the form of theories and laws (National Science Teachers Association, 2000).

The current standards representing the learning goals for students in the United States, and more specifically in Minnesota, identify the development of an understanding of NOS as a specific outcome. The American Association for the Advancement of the Sciences (AAAS) is conducting a long-term research study focusing on developing scientifically literate American citizens. Project 2061 includes recommendations for learning goals, outcomes, and appropriate assessments to support Americans in becoming scientifically literate. Furthermore, teacher professional development is highlighted as a critical factor for improving student achievement (American Association for the Advancement of Science, 2010).

Nature of science is a fundamental pillar of scientific literacy and scientific epistemology, which refers to science as a way of knowing (Lederman, N.G., 1992). Project 2061 describes NOS as the study of how scientific knowledge and thought are generated through observation, inference, and validation. AAAS makes it clear that a fundamental understanding of how and why science makes claims, another way of describing nature of science, is firmly a requisite for scientific literacy (American Association for the Advancement of Science, 2010). It is unreasonable to expect students to understand scientific studies, draw inferences, and make conclusions if they have not exercised the logical foundation on which scientific literacy is built.

The Minnesota Department of Education (MDE) includes state learning standards for science education. There are eleven standards specific to the nature of science in the curriculum guide for high school students (Minnesota Department of Education, 2009). The standards that are being investigated in this study are directly from the Minnesota State Science Standards. Standards 9.1.1.1.2 through 9.1.1.1.7 were selected as one complete strand from the Minnesota State Science Standards that specifically address nature of science topics and are listed in Table 1.

Table 1

Nature of Science Language in the Minnesota State Science Standards

Standard Code:	Benchmark:
9.1.1.1.2	Understand that scientists conduct investigations for a variety of reasons, including: to discover new aspects of the natural world, to explain observed phenomena, to test the conclusions of prior investigations, or to test the predictions of current theories.
9.1.1.1.3	Explain how the traditions and norms of science define the bounds of professional scientific practice and reveal instances of scientific error or misconduct.
9.1.1.1.4	Explain how societal and scientific ethics impact research practices.
9.1.1.1.5	Identify sources of bias and explain how bias might influence the direction of research and the interpretation of data.
9.1.1.1.6	Describe how changes in scientific knowledge generally occur in incremental steps that include and build on earlier knowledge.
9.1.1.1.7	Explain how scientific and technological innovations – as well as new evidence – can challenge portions of, or entire accepted theories and models including, but not limited to: atomic theory, etc…

Justification for the Inclusion of NOS Topics in Science Education

Science in schools is uniquely tangled with social, political, and economic issues present in greater society. Climate change, evolution, material science, and healthcare are just a few examples of relevant topics that students will encounter. It is important that a student exiting the P-12 educational system be able to examine, critique, and consider the validity of scientific claims (Tytler & Symington, 2006). Students with an underdeveloped view of NOS topics often do not identify that scientific claims can be challenged causing them to disengage from discussion and evaluation of available evidence (McDonald, 2010). Teaching nature of science also helps dispel common misconceptions regarding controversial scientific topics (Schwartz, Lederman & Abd-El-

Khalick, 2012). For example, Schwartz, Lederman, & Abd-El-Khalick (2012) indicate that NOS helps students understand the level of scientific support necessary, evidence required, and academic rigor needed to classify evolution as a scientific theory. Rather than simply using evidence to support the theory of evolution, it was more effective to teach students the relationship between hypotheses, theories, and laws: all critical components of NOS. This understanding prevents the common sort of colloquialism like “its just a theory”, which embodies an underdeveloped attitude and understanding of NOS. It is imperative that students develop an understanding of the nature of science while in school, so that they can make informed decisions on those topics, and fulfill their civic responsibility (Karakas, 2010).

It is clear that students must leave the P-12 educational system with a well-developed understanding of NOS. In order to accomplish this goal, science teachers need to have an appropriate and correct understanding of NOS themselves. Beyond simply understanding NOS, teachers need to actively incorporate NOS topics into their lessons to guarantee that students have the opportunity to develop knowledge of NOS (Karakas, 2011). In order to teach NOS effectively teachers need to have sufficient understanding of NOS, know how to implement a curriculum that supports NOS outcomes, and finally prioritize NOS outcomes over other classroom needs (Karakas, 2011).

New teachers are in an especially difficult situation with regards to NOS. A study of five high school biology teachers found that experienced teachers, roughly fifteen years of teaching experience, had a significantly more developed understanding of NOS compared to beginning teachers, those with less than five years of experience (Lederman, 1999). The teachers involved with the study were observed for an entire academic year and data collected included classroom observations, open-ended surveys, interviews and analysis of lesson plans. The novice teachers were not simply oblivious to NOS topics. Instead, they were choosing not to teach NOS in favor of other priorities in the classroom. New teachers were likely to focus on classroom management and keeping students' interest in daily topics for the entirety of a class period rather than exploring nature of science topics (Lederman, 1999).

An additional obstacle which beginning teachers face when teaching NOS topics is the gap in time between exposure to NOS topics in their teacher preparation program and their current instructional position. Research indicates that pre-service education focusing on nature of science successfully informs the views of pre-service teachers (Akerson, Abd-El-Khalick, & Lederman, 2000). The NOS views of pre-service teachers were examined throughout their preparation and into their first year of teaching. New teachers' views of NOS, although at one point aligned with the definition of nature of science outlined in this research, reverted back to an uniformed status within five months of teaching, similar to before they had any training on nature of science topics (Akerson, Morrison, & McDuffie, 2005).

Teaching NOS

Interest regarding the role of nature of science in education has led to a number of pedagogical approaches being implemented over the past several decades. The original method was simply an implicit approach. Some scholars believe that students will generate an understanding of nature of science simply by engaging in scientific activity. This approach suggests that teaching science to students, allowing them to actually do science in the classroom, will allow students to develop an understanding of nature of science (Gabel, Rubba, & Franz, 1977). Further research indicated that implicit instruction is not a sufficient pedagogical technique for including nature of science outcomes within a curriculum (Oliveira, Akerson, Pongsanon, Genel, & Colak, 2012). There are a variety of approaches and instructional strategies that science educators can include within a curriculum design in order to support the acquisition of scientific epistemology. These techniques include explicit instruction, inquiry based science, argumentation and the use of history of science to provide contextual examples that students can utilize to apply nature of science reasoning.

An **explicit approach** to teaching nature of science includes specific curricula components to address nature of science outcomes (Akerson, Abd-El-Khalick, & Lederman, 2000; Cil, 2014). Through this approach, instructors will individually identify aspects of the nature of science to address, potentially using one of the other techniques listed above to teach the material. The distinction of an explicit approach is simply the decision to address nature of science as a part of the relevant coursework. Some research indicates an explicit approach improves understanding, appreciation, and perspective regarding NOS topics from elementary students through pre-service teachers (Akerson, Abd-El-Khalick, & Lederman, 2000; Khishfe & Abd-El-Khalick, 2003).

Inquiry represents an opportunity for students to implement several of the components discussed when defining nature of science. Inquiry involves creativity when a question is identified, a method is designed for the collection of data, and when analyzing results. On top of creativity, inquiry is based on the use of empirical observations to provide evidence to support or refute a hypothesis (National Science

Teachers Association, 2004). There are several different levels of inquiry that can be implemented in a high-school classroom. The skills required to complete a full or open inquiry, which is the type of inquiry that most resembles professional scientists work, may require scaffold skills. Structured inquiry is largely guided by the instructor and students develop methods to reach a specific end point. In between structured and open inquiry is guided inquiry. Guided inquiry allows the teacher to provide a lesser degree of support than structured inquiry while still providing some level of assistance to students (Martin-Hansen, 2002). These types of inquiry exist on a continuum where a "cook-book" activity is an example of a structured inquiry on one end of the continuum. The other end would be exemplified by an investigation where students ask an original research question and maintain control of the process from beginning to end (Krystyniak, 2001) Human bias is present due to decisions made regarding experimental design. Inquiry combined with an explicit approach would allow for instructors to use the inquiry activities as a foundation for discussing nature of science. The use of these two combined techniques helps students understand the tentative nature of science rather than reinforcing the view that science is a static body of knowledge (Oliveira, et al., 2012; Akerson & Hanuscin, 2007).

Argumentation is the practice of directly teaching students the components of arguments as well as skill development in terms of forming and evaluating arguments (McDonald, 2010; Sampson, Enderle & Grooms, 2013). McDonald describes a classroom, highlighting the effectiveness of argumentation, where pre-service teachers are engaged in explicit argumentation. The pre-service teachers were involved in an activity where observations, inferences, and conclusions were made. During this process, the instructor, using direct instruction, highlighted the tentativeness of scientific knowledge as well as the distinction between laws, theories, and hypotheses. Students then engaged in forming and defending those inferences and conclusions. These activities required students to assess the validity, function, and application of evidence within scientific arguments and participate in scientific thought beyond simply engaging in core content. The evidence was based off of empirical observations and the students adjusted scientific explanations based off of the new evidence (McDonald, 2010). These activities employ multiple facets of the definition of nature of science.

History of science describes an approach where learners of science reproduce historical experiments, investigate results and data from historical experiments, or learn how new technology, information, and understanding has led to paradigm shifts in scientific knowledge (Hocieminoglu, 2014). The use of historical references readily lends itself to explicit instruction. There are copious examples of creativity, subjective theories, and biases throughout history. More importantly, a historical perspective brings the tentative nature of science into focus. A unique subset of this genre is the use of scientific errors to teach nature of science. If the goal is to learn what the nature of science is, historical errors can help distinguish what does not meet the rigorous definition. Scientific error reinforces the importance of proper epistemological claims (Allchin, 2012). Ultimately applying NOS concepts to the context of contemporary cases, actual issues, and topics with which our society is currently engaged, is an ideal end goal. Secondly, current issues in science frequently motivate more engaged discussion with high school students (Allchin, Anderson, & Nielsen, 2014).

Summary

Nature of science has been a part of the discussion regarding best practice in science education since the beginning of the 20th century. Scientific literacy is a major benefit that justifies the presence of nature of science topics within a high school, and specifically chemistry, curriculum. The need to address NOS outcomes in science curricula is clear based on the assumption that scientific literacy is a primary goal for science education. Teachers' knowledge, views, and understandings of NOS play a significant role in determining the opportunities students have to reach the NOS objectives outlined in AAAS Project 2061 and the Minnesota State Science Standards (American Association for the Advancement of Science, 2010; Minnesota Department of Education, 2009). A variety of pedagogical methods have been correlated with teaching nature of science in an effective manner. Focusing on Minnesota chemistry teachers, the specific standards addressed, and pedagogical approaches implemented, this research will provide clarity on how NOS is being approached in chemistry classrooms.

Chapter 3

METHODOLOGY

Introduction

This research will investigate the practices of teachers with regards to nature of science topics within their classroom instruction. The first research question will gather data on the frequency that six different nature of science standards are addressed and the pedagogical methods being used to incorporate nature of science content into general chemistry curriculum. The second research question will compare teaching experience, engagement in professional development surrounding nature of science, and teacher preparation programs to the tendency of a teacher to include nature of science topics in a general chemistry high school curriculum.

Participants

The participants in this research will be high school chemistry teachers in Minnesota. A list of people licensed to teach chemistry in grades 9-12 will be obtained from the Minnesota Department of Education (MDE). According to MDE, there are 9 schools that cover all grades K-12 schools, 221 schools with grades 7-12, and 222 schools that enroll students only in grades 9-12 in Minnesota (Minnesota Department of Education, 2015a). This totals 452 schools that would likely have a chemistry teacher on staff. A survey will be sent electronically to all members of this list. Data will only be used from Minnesota public high schools as they are required by law to address the Minnesota State Standards for science. In addition, teachers who currently teach a general chemistry course or have taught a general chemistry course in the last three academic years will be targeted for participation.

Survey Instrument

The instrument for this research will collect both demographic information and data regarding teachers practice regarding nature of science concepts. The survey includes a maximum of 29 questions, that includes 10 multiple choice and 6 free response questions. 6 demographic questions, some of which have follow up questions, will solicit data regarding the type of degree or licensure the survey respondent has obtained as well as when and where the degree was earned, number of years of experience teaching science and subjects in which the survey participant has experience teaching. There are two free response questions at the end of the survey where the participant is asked to identify any roadblocks encountered when teaching nature of science topics as well as the opportunity to identify tools that would support the instruction of nature of science topics. Demographic information such as name, school, and personal contact information has been left out to ensure anonymity.

All participants will complete the same survey, however the individual experience will have a small amount of variability based on the participant's experience and educational background. If it is reported at the beginning of the survey that the person participating does not currently teach chemistry, and has not done so within the last three academic years, the survey will end. Qualified participants will continue on to the main portion of the survey. The next block of questions collects information about the survey participant. Experience in subjects taught, duration of teaching career, experience in public versus private schools, and the date of initial licensure will be collected. The rest of the survey allows participants to select from a list of nature of science standards from the Minnesota State Science Standards. Participants will be instructed to identify which of the nature of science standards are addressed in their general chemistry courses. There are also a number of common pedagogical techniques listed as options for participants to select as the method(s) used to teach nature of science in their classroom. The last block of questions in the survey collect information regarding the assessment of nature of science standards. Participants are also asked about perceived roadblocks to teaching nature of science.

The survey instrument will be administered online through Qualtrix. The tool will be completely anonymous. Qualtrix is able to separate the survey responses from the email address identifying a participant. There is no personal information collected in the survey that could be used to identify participants.

Research Design

The initial survey will be distributed in January 2016. The survey will close 14 days after the initial distribution of the survey. Participants will be contacted up to three times regarding the survey. Once a potential participant has completed the survey they will be removed from future email contact. The initial survey will include a link to the Qualtrix survey and a brief request for completion. The second request for participation will be sent after one week has passed. The final request for participation will be sent 48 hours before the survey closes. After the survey closes the results will be analyzed to determine similarities and differences between the practices of responding teachers.

Data Analysis

The survey data will be analyzed for relationships between the tendency to include instruction on nature of science topics and instructor information such as years of teaching experience, engagement in professional development on nature of science topics, and teacher preparation program. A Pearson correlation will be used to determine if there is a meaningful relationship between the tendency to include nature of science topics in general chemistry instruction and each of the variables: teaching experience, engagement in professional development, and number of hours of professional development on nature of science topics. An ANOVA table will be used to determine if there is a meaningful difference between teacher preparation programs compared to the tendency to include nature of science topics in instruction. The frequency of the six nature of science standards represented in Table 1 will be tabulated to evaluate the rate they are being addressed in general chemistry classes. Finally, the pedagogical methods currently used by the participating teachers will be compared to the methods learned in their teacher preparation programs.

Summary

All teachers licensed for chemistry grades 9-12 in Minnesota will be solicited to participate in this research regarding their instructional practice regarding nature of science standards in their classrooms. The data will identify which standards are taught in chemistry classrooms as well as the pedagogical methods used to deliver this content to students. The results of this research will provide insight into teachers' adherence to the Minnesota State NOS Science Standards, and the strategies they implement in their classrooms for improving their students understanding of science. This information can be used to make suggestions to both teacher preparation programs for the education of future high school chemistry teachers and to identify topics and opportunities for professional development for veteran teachers.

CHAPTER 4

RESULTS

Introduction

Responding to a 29 question online survey, Minnesota high school chemistry teachers answered questions regarding their own practice of teaching nature of science topics in general chemistry classes. Demographic information, including the number of years of teaching experience, the institution that recommended them for licensure, and professional development in the area of nature of science was also collected. Surveys were not included in the data analysis if the teachers have not taught general chemistry within the last three academic years, teach in private schools, or did not answer all of the questions in the survey.

The data collected focuses on answering the following two research questions:

- Which of the nature of science standards in this survey do Minnesota chemistry teachers most frequently address, and how are they included in their classes?
- What effects do teaching experience, teacher preparation, and in-service professional development have on chemistry teacher practice regarding nature of science?

Results

Survey Administration

The survey was distributed via email to a list of chemistry teachers licensed in Minnesota. The list was obtained from the Minnesota Department of Education. The survey was sent to 1034 email addresses. 503 of those emails were opened. Of the 102 people that started the survey 52 participants completed the survey. The response rate was 10.3% of the 503 emails that were opened. Data was filtered to include responses only from teachers who are either currently teaching at least one section of general chemistry or have done so in the past three academic years. Another filter was applied to the data to only include responses from Minnesota Public School teachers. Private schools are not legally obligated to follow the 2009 Minnesota State Science standards. This filter ensures that the data used for analysis is from teachers, who should be planning for, and meeting, these standards. Participants answered questions about their own practices when implementing nature of science standards in their classrooms.

Demographic Information

Of the 52 participants in the survey, the average number of years teaching is 11 years with a median of 9 years teaching. In terms of advanced degrees 33% of the sample reported earning a Master of Science degree, 50% of the sample reported earning a Master of Education degree, and 2% of the sample report earning a Masters of Administration degree. Participants reported earning their license from one of 28 different institutions, with completion occurring between 1972 and 2015.

Research Question 1

- **What effects do teaching experience, teacher preparation, and in-service professional development have on chemistry teacher practice regarding nature of science?**

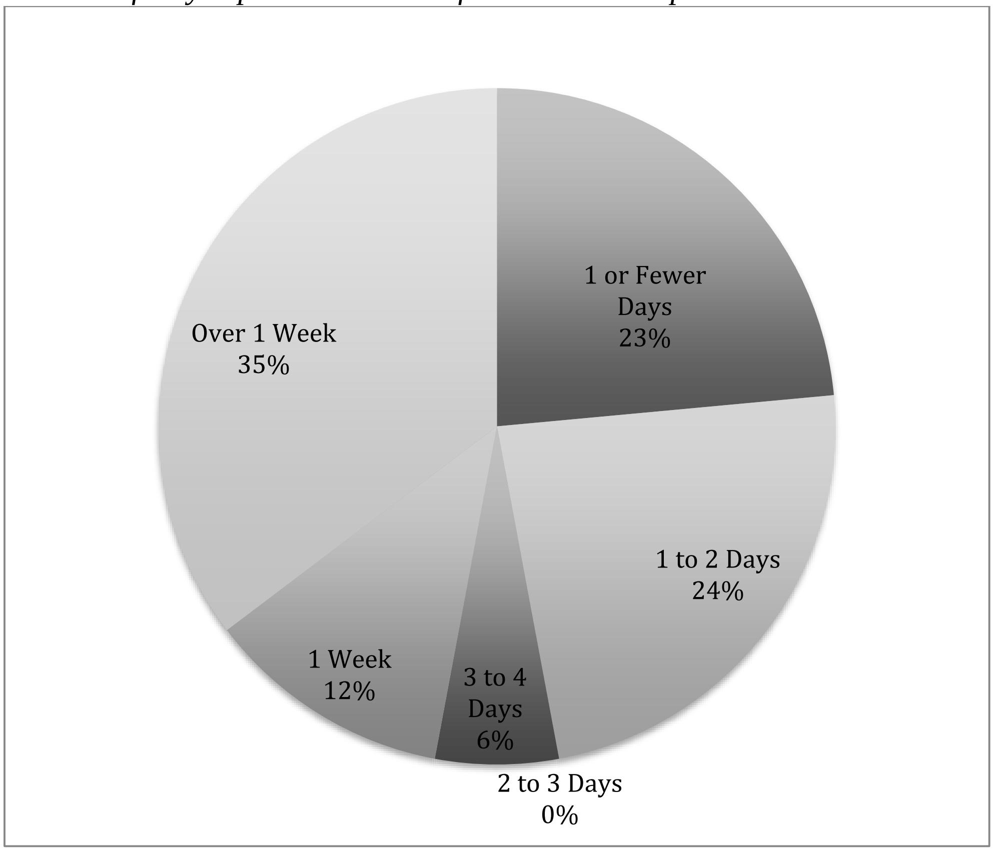
Survey participants reported information regarding the specific nature of science standards that they include in their curriculum as well the number of times a nature of science standard is addressed each semester. A Pearson Correlation was applied to determine if there is a relationship between number of years of chemistry teaching experience and the number of times nature of science topics are included per semester. The Pearson Correlation (.108, p=.452) suggests that there is almost no correlation between these two variables, however the p value indicates that no reliable conclusion can be made.

The participants were separated into two groups based on teaching experience. The first group contained teachers with zero to five years of teaching experience and the second group reported more than five years of teaching experience. The two groups are novice and experienced teachers respectively. The novice group averaged 5.3 inclusions of nature of science per semester and the experienced group averaged 5.4. The difference between these two values was compared using a t-test to determine if there was a significant level of difference (p = .908). Based on the p value, there is no meaningful difference between the group of novice and experienced teachers in terms of the number of times they include nature of science topics each semester.

Participation in professional development on nature of science topics, total number of hours spent on professional development, and the identification of courses that included nature of science topics during their teacher preparation program were also reported. Of the survey respondents, 71% have engaged in professional development with a focus on nature of science. On average, teachers reported 31 hours of professional development with a median of 20 hours. This data is more accessible when interpreted as days of professional development. Assuming that an average day of professional development is equal to six hours, the mean value is just over five days and the median value is slightly over three days. The distribution of professional development completed in terms of days is represented in Figure 1. The pie chart is divided into six sections based on one through five days of professional development and the sixth section represents greater than one week of professional development. There is a noticeable trough for the middle values on this chart, 47% of participants have completed two or fewer days of professional development while those with one or more weeks make up another 47% of the sample.

Figure 1

Number of Days Spent on NOS Professional Development



A Pearson correlation was used to evaluate the relationship between participating in nature of science professional development and the number of times a nature of science topic is included in class by the instructor per semester. A similar relationship was examined by comparing the total number of hours of professional development focused on nature of science and the number of inclusions of nature of science per semester. A weak positive correlation (.309, p=0.027) was found between participation in professional development on nature of science and the number of times a nature of science topic is included in their curriculum per semester (Table 2). While a positive correlation, it is not strong enough to completely refute the null hypothesis that engagement in professional development on nature of science topics does not correspond to an increase in average number of inclusions of nature of science per semester. The N value for three out of the four quadrants in Table 2 is 51 because one participant reported that they include nature of science topics "umpteen" times on average per semester. There was not an effective way to quantify this value so this participant was not included in this Pearson correlation.

Table 2

Correlation between Professional Development Participation and Number of NOS Inclusions per Semester.

		Participation in NOS Prof. Dev.	**Inclusions Per Semester**
Participation in NOS Prof. Dev.	Pearson Correlation	1	.309
	Sig		.027
	N	52	51
Inclusions Per Semester	Pearson Correlation	.309	1
	Sig	.027	
	N	51	51

Though there is a weak correlation between having engaged in professional development on nature of science and including nature of science topics in general chemistry curriculum, data did not indicate that the amount of time spent in professional development was statistically significant. A weak correlation (.259, p=.146) is suggested from the Pearson test but is inconclusive based on the p value.

Data regarding how nature of science was included in the participants teacher preparation programs was also solicited. The three primary types of courses included in a typical chemistry teacher preparation program are chemistry content, pedagogy, and science methods courses. Science education courses (79%) were the most common place in a teacher preparation curriculum for the sampled chemistry teachers to experience nature of science topics. Pedagogy classes (25%) included the fewest affirmative responses and 54% of chemistry teachers had chemistry coursework that included nature of science.

Data was collected regarding pedagogical methods learned during teacher preparation programs, specifically pertaining to nature of science topics. Table 3 is a summary of the percent of participants that learned each method in their teacher preparation programs.

Table 3

Methods for Teaching NOS Topics Learned in Teacher Preparation Programs

Pedagogical Method	Explanation	% of Participants
Explicit Instruction:	Curriculum includes specific components to solely address nature of science outcomes.	67%
Implicit Instruction:	Students learn nature of science by engaging in scientific activity not specific to NOS outcomes.	77%
Argumentation:	Students form and defend conclusions during in-class discourse based on given scientific premises.	20%
Inquiry:	Investigation of an original hypothesis through the collection of empirical evidence and observations.	77%
Historical Perspective:	The use of historical examples to highlight paradigm shifts and development of new knowledge.	56%
Teaching through Scientific Error:	A subset of "Historical Perspective" that focuses on historical errors in science. Students consider the justification or knowledge needed to correct the original misconception.	37%

These pedagogical methods represent the toolbox that teachers are collecting during their education to include nature of science topics in their own classrooms when they become teachers.

The relationship between the number of inclusions of nature of science topics per semester and the institution that recommended a current teacher for licensure was tested for correlation to explore if any higher education institutions prepare teachers that have a greater tendency to include nature of science topics in their curriculum. An ANOVA table, Table 4, was used to compare the schools to determine if there is a statistically significant difference between tendencies of the participating teachers to include nature of science topics in their curriculum. Based on the sample used for this study, there is no significant difference between the instituations.

Table 4

ANOVA Analysis of the Relationship Between Licensing Institution and Teachers' Inclusion of NOS Topics in Their Chemistry Courses

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	501.056	26	19.271	.852	.656
Within Groups	542.954	24	22.623		
Total	1044.010	50			

Research Question 2

- **Which of the nature of science standards in this survey do Minnesota chemistry teachers most frequently address, and how are they included in their classes?**

Data was collected regarding selected Minnesota State Science Standards 9.1.1.1.2-9.1.1.1.7. Participants reported which of the included standards are addressed in their general chemistry.

Table 5

NOS Standards Addressed in General Chemistry

Standard Code:	Benchmark:	% of Teachers who taught this standard
9.1.1.1.2	Understand that scientists conduct investigations for a variety of reasons, including: to discover new aspects of the natural world, to explain observed phenomena, to test the conclusions of prior investigations, or to test the predictions of current theories.	85%
9.1.1.1.3	Explain how the traditions and norms of science define the bounds of professional scientific practice and reveal instances of scientific error or misconduct.	39%
9.1.1.1.4	Explain how societal and scientific ethics impact research practices.	39%
9.1.1.1.5	Identify sources of bias and explain how bias might influence the direction of research and the interpretation of data.	54%
9.1.1.1.6	Describe how changes in scientific knowledge generally occur in incremental steps that include and build on earlier knowledge.	92%
9.1.1.1.7	Explain how scientific and technological innovations – as well as new evidence – can challenge portions of, or entire accepted theories and models including, but not limited to: atomic theory, etc…	92%

A sizeable spread is present between the most and least frequently addressed standard. Of the reporting teachers, 92% included two of the six standards (9.1.1.1.6 and 9.1.1.1.7) in their general chemistry curriculum, while the standards least frequently addressed, 39% of the time, were 9.1.1.1.3 and 9.1.1.1.4. The participants were asked to disclose the number of times they included nature of science in their curriculum per semester. The mean is 5.1 times per semester with a median value of four times per semester. Only one participant reported zero instances of nature of science topics in their instruction. The most frequently occurring value was two times per semester. The participants were also able to indicate which pedagogical methods they use to implement nature of science content into their classes. Table 6 includes both the percent of teachers that reported using each method and the percent of teachers that learned about a particular method in their teacher preparation programs.

Table 6

Pedagogical Methods for NOS Implemented by Teachers

Pedagogical Method	Learned	Taught	Significance
Explicit Instruction	67%	77%	p = 0.127
Implicit Instruction	77%	81%	p = 0.308
Argumentation	20%	31%	p = 0.099
Inquiry	77%	75%	p = 0.405
Historical Perspective	56%	79%	p = 0.006
Teaching through Scientific Error	37%	50%	p = 0.090

Using a Z-test, the only pedagogical technique that demonstrates a significant difference in the 95^{th} percentile is historical perspective. More participants reported using historical perspective than the number of participants that learned the method in their teacher preparation program. If the level of significance is lowered to the 90^{th} percentile of certainty argumentation and teaching through scientific error both demonstrate a significant difference between the number of participants that learned the techniques in school versus the number that used them in their teaching practice.

The final two questions on the survey asked participants to report roadblocks preventing them from including nature of science topics in their general chemistry courses and what type of support would allow them to include more nature of science content in their instruction. Content analysis was used to identify patterns in the responses.

Table 7

Content Analysis of Reported Roadblocks to NOS Instruction

Theme	Example	Percent of Responses N=49
Time	"Time"	55%
Curriculum Control	"Too many standards. Is this one more valuable than content standards?	18%
Students	"Students ability to problem solve when not given exact directions" and "Students seem to want to just be told, not think about scientific problems solving on their own."	12%
Other	"The current media culture and the flaccid representation of science; including poorly written textbooks."	14%

The most common roadblock when attempting to include nature of science topics in their curriculum was the lack of time, 55% of responses. 18% of the participants identified that the science content standards require too much time and prevent the nature of science standards from being taught in general chemistry. Concern regarding student's ability to learn and understand nature of science content as well as class size impairing the teacher's ability to meet the needs of each student in their class, consisted of 12% of the responses.

Table 8

Content Analysis of Reported Potential Support for NOS instruction

Theme	Example	Percent of Responses N=44
Pre-Made Activities and Curriculum	"ways to incorporate the nature of science more effectively into existing lessons."	36%
Additional Time	"More time!"	20%
Professional Development	"Additional workshops and online tools"	11%
Fewer Content Standards	"Less specific standards regarding the other areas of science so more time can be used in a more student driven approach. We cannot do this in chemistry or biology currently because the content specific standards take too much time even with direct instruction"	11%
Additional Resources / Lab Equipment	"More resources and smaller class sizes"	7%
Additional Support in Other Science Classes	"More emphasis in other science courses."	7%
Other	"a clear understanding of what is expected from these standards and what grade level is most appropriate"	7%

Survey participants were also asked to identify support and tools that would support the inclusion of nature of science in their classrooms. The most common request, 36% of responses, is for the creation and availability of pre-made activities, curriculum, and assessments that can be implemented in an already existing curriculum. More time was requested by 20% of participants. Other requests for support include more professional development (11%), fewer content standards (11%), more lab equipment and resources (7%), and increased nature of science support in other science classes within their department (7%).

Summary

The data support the claim that Minnesota chemistry teachers are aware of nature of science standards and are committed to including them in their general chemistry curriculum. Two state standards have a completion rate of over 90% and a third has a completion rate of 85% (Table 5). The methods used to support student learning of nature of science are similar to those learned in teacher preparation programs, though used at a higher rate (Table 6). A weak, yet reliable, correlation was also found between involvement in nature of science professional development and the number of times nature of science content is included by a general chemistry instructor (Table 2). This data provides a snapshot of the current practices of chemistry teachers in Minnesota surrounding nature of science topics.

CHAPTER 5

DISCUSSION

Introduction

The purpose of this study is to investigate the habits, practices, and experiences of Minnesota chemistry teachers regarding the inclusion of nature of science topics as part of a general chemistry high school curriculum. This data will identify how the nature of science standards, a component of the 2009 Minnesota state science standards, are included in actual chemistry classrooms. Teacher's experiences, practices, and views on challenges and opportunities surrounding the instruction of nature of science topics will inform possible pathways to support the development of teacher understanding of, and ability to teach, nature of science content at the high school level.

The research questions in this study are:

- Which of the nature of science standards in this survey do Minnesota chemistry teachers most frequently address, and how are they included in their classes?
- What effects do teaching experience, teacher preparation, and in-service professional development have on chemistry teacher practice regarding nature of science?

Nature of science is defined in the survey instrument as: "Nature of Science, for the purposes of this survey, is defined as the underlying principles for science as a way of knowing and characteristics of scientific knowledge (Akerson, et al., 2000; Karakas, 2011; Lederman, Lederman, & Antink, 2013). " A major challenge in studying this topic is that there is not a single universally accepted definition for nature of science. Many different interpretations of the concept exist both as an interdisciplinary evaluation and within a single discipline such as chemistry or education. While nature of science was defined explicitly as part of the survey in this research, each participant undoubtedly had a slightly different understanding of the concept that existed beyond the definition. This makes implementing standards for nature of science especially challenging, as each instructor may understand the language, and epistemology, of the topic in a unique manner.

An education rich in nature of science content leads to scientifically literate individuals (Karakas, 2010). This is the most significant argument in favor of including nature of science topics in chemistry curriculum. Common misconceptions are readily dispelled and students proactively engage in scientific thinking when taught how to engage with the nature of science (Schwartz, Lederman & Abd-El-Khalick, 2012). According to current literature, teachers are aware of the importance of nature of science topics as part of science education, but frequently do not include this content in their classrooms (Karakas, 2011). There are a variety of beneficial pedagogical techniques that can be used to instruct students on nature of science topics. These techniques were defined in Table 3 and were included as options in the research survey.

Discussion and Conclusions

- Which of the nature of science standards in this survey do Minnesota chemistry teachers most frequently address, and how are they included in their classes?

This research question involves the frequency with which nature of standards are being taught within Minnesota chemistry classrooms. The perception that teachers prioritize other classroom needs over the inclusion of nature of science topics (Karakas, 2011; Lederman, 1998) is both true, and yet misleading. Two different standards on the survey were taught by 92% of teachers. A third standard was taught by 85% of teachers (Table 6). These standards overlap content that is included in every general chemistry course. For example, during instruction on the subatomic particles in atoms it is convenient and relevant to discuss the historical models of the atom as well as the experiments that demonstrated the presence of previously unknown subatomic particles or structural character. Including these topics does not require a chemistry teacher to drastically alter their curriculum but allows them to include three standards from Table 6: 9.1.1.1.2, 9.1.1.1.6, and 9.1.1.1.7. One interpretation of this data is that Minnesota chemistry teachers are willing to include nature of science content when it does not require the neglect of content standards. This tendency was shared as a response when participants were asked for potential support in teaching nature of science via comments like "Better Curriculum that ties in NOS with other standards." The high percentage of participants that include three of the standards found in Table 5 demonstrate that a majority of teachers sampled are including some nature of science content in their general chemistry classes. Only one participating teacher indicated that they never include nature of science content in their curriculum.

Over 75% of the participating teachers use four of the methods found in Table 3. Explicit instruction, implicit instruction, inquiry, and historical perspective are all methods that most of the responding teachers are comfortable enough to use in their own classes. Teaching through scientific error is used by 50% of teachers in this study and argumentation is the least common pedagogical method with a usage rate of 31% by participants. Teaching through scientific error and argumentation are both methods that are more specific to teaching nature of science than the other four, more commonly used, methods. They are not as effective at teaching chemistry content alone or in conjunction with nature of science content. Implicit, explicit, inquiry, and historical method are all pedagogical methods which can be used with content that is not specifically based in nature of science to include some components of nature of science. This is a possible explanation for the discrepancy between the number of teachers that use each method.

An interesting phenomenon that appeared in the data involves the six different pedagogical methods associated with teaching nature of science (Table 6). There was an increase in five out of the six methods when comparing the methods learned in teacher preparation programs and the methods currently being utilized in the teacher's practice. The largest, and only significant ($p = .006$), increase was observed with the method "historical perspective." It increased from 59% of participants learning the method in their teacher preparation programs to 79% of participants using the method in their classroom. "Argumentation" and "Teaching through scientific error" demonstrated a significant increase when the Z-test significance level was lowered to .10. Whether the mechanism responsible for these increases is from professional development, mentoring, or another explanation there is evidence that Minnesota chemistry teachers continue to advance their skill-sets for teaching nature of science topics during their active years of teaching.

- What effects do teaching experience, teacher preparation, and in-service professional development have on chemistry teacher practice regarding nature of science?

Four variables were analyzed for correlations with the rate teachers included nature of science topics as part of a general chemistry curriculum. Participating teachers reported the average number of times they include nature of science topics per semester and this value was used to represent the rate of inclusion of nature of science. The four variables investigated for a relationship were previous professional development on nature of science, the number of hours of professional development on nature of science, years of experience as a high school chemistry teacher, and institution of licensure.

Professional development on nature of science topics was the only variable in this study found to be significant when compared to the number of times nature of science topics are included in a semester of general chemistry (Table 2). The Pearson Correlation between these two variables demonstrated a weak positive correlation (. 309, p=.027). The correlation is reliable as it is significant to the 95th percentile. The positive correlation indicates that engagement in professional development on nature of science increases the practice of teachers to include nature of science topics in general chemistry. The number of hours of professional development did not conclusively demonstrate a correlation with the practice of including nature of science topics in curriculum (.259, p=.146). A weak positive correlation suggests that a greater number of hours of professional development will increase the amount of nature of science instruction a teacher includes in general chemistry. However, the p value is too low to give this claim statistical significance.

The division of the sample of participants into novice teachers and experienced teachers did not demonstrate a significant difference in the practice of including nature of science content into general chemistry curriculum. The mean number for inclusions of nature of science per semester was 5.3 and 5.4 for novice and experienced teachers respectively, showing no difference (p=.908). Previous research that suggests that teachers with less than five years of experience tend to prioritize content needs over nature of science content (Lederman, 1998) was not supported in this study. There was no significant correlation between the number of years of teaching experience and instances of the inclusion of nature of science topics. The data gathered in this study does not definitively refute this claim, however the similar means of 5.3 and 5.4 (p=.908) between the novice and experience teacher groups suggest that novice and experienced teachers include nature of science topics a similar number of times each semester.

Years of experience teaching chemistry had almost no correlation with the number of times participants include nature of science topics per semester according to a Pearson Correlation (.108, p=.452). The low value for positive correlation is not statistically reliable so this research cannot make claim that the affect the number of years of experience has on the tendency to include nature of science content.

Licensing institutions approach nature of science with their pre-service teachers differently. Seventy-nine percent of participating teachers reported that they experienced nature of science content most frequently in science education courses. Science and education courses were reported as including nature of science topics by 54% and 25% of participants respectively. An ANOVA table was used to determine if there is a significant difference between the practices of teachers based on where they completed their teaching preparation (Table 4). The relatively high p value of p=.656 indicates that there is not a meaningful difference between the mean value for number of instances of nature of science included per semester when compared by the licensing institution of the teacher.

The following two questions were included in the survey to collect qualitative information regarding the inclusion of nature of science topics in their classroom.

- What is a roadblock you face to effectively teach nature of science in your classroom?
- What support or tools do you need to more effectively teach nature of science?

Responses regarding the roadblocks teachers face when attempting to include nature of science instruction are represented on Table 7. Overwhelmingly, the most common response was a lack of instructional time, with 55% of participating teachers indicating that they do not have enough time to include the proper amount of nature of science instruction because of other chemistry content like “Needing to teach other science standards pertaining to a specific content area.” Of the participants, 18% reported that the content standards are prioritized over the nature of science standards because they are more readily testable e.g. “Curriculum focused on measured (i.e. tested) outcomes.” The literature available on the importance of nature of science in secondary classrooms makes an effective argument that it is at least as important as content standards, if not more so (Tytler, 2007). Students trained in nature of science will be able to make informed, responsible decisions and have the potential to become engaged scientifically literate citizens (Karakas, 2010; Tytler & Symington, 2006). The goals of science education need to be considered when prioritizing content standards versus nature of science standards.

Despite 71% of participating teachers indicating that they have completed professional development specific to nature of science, the most common request, 36% of responses, was for pre-made lesson plans and assessments to more effectively include nature of science in their curriculum. This is not only the most common request for support, but also largely the most feasible. A request for more time to teach chemistry (20%) and fewer content standards (11%) would need to be considered outside of professional development or teacher preparation programs. A request for more time would involve changes to the length of chemistry classes on a daily or calendar basis are an unlikely to an option for a significant number of schools. Secondly, smaller class sizes would undoubtedly yield some instructional benefits, but it is not necessarily the most reasonable solution to present as, again, this change would need to be instituted at a school or district level.

Limitations

- The survey response rate was roughly 10%. The total number of responses from participants that met the demographic requirements was 52. While still a useful number of responses, a higher number would have provided more certainty in making claims regarding the current practice of Minnesota chemistry teachers.

- The list of licensed chemistry teachers obtained from the Minnesota Department of Education was only partially complete in terms of contact information. Email addresses were available for only 50% of the list. It is also unclear how many of the email addresses were current. Only 503 of the over 1034 emails sent with survey information were opened according to Qualtrics.
- Teachers that were willing to complete this survey may have been subject to a selection bias. Teachers that practice the inclusion of nature of science content into their curriculum are possibly more likely to take the time to share their practices. Because of this, the sample may not be representative of the entire population of Minnesota chemistry teachers.
- Language involved with the discussion of nature of science is complicated at the very least. The explanation of the concept is complicated and involves at least six to eight sub-concepts. Due to the complexity of the topic, it is assumed that each participant interpreted the survey in a unique way. Bias in comprehending survey questions may have skewed the data.
- Teachers are self-reporting their practices surrounding state science standards and classroom practice. It was necessary to provide options to a number of the questions that the participating teachers could select. Including this type of information on standards completed and pedagogical methods may have seeded beliefs in the teachers regarding their own perception of their practices. An open study may have avoided

this limitation, but it also may have been an incentive for teachers not to participate due to a significantly increased time commitment.

Recommendations

The strongest relationship (.309, p=.027) found in this study is between engagement in professional development on nature of science topics and the practice of including nature of science by teachers of general chemistry, though it is a weak correlation. Of the participating group, 29% have not had the opportunity to engage in professional development on this topic. An organization such as the Minnesota chapter of the NSTA could provide a statewide professional development opportunity focused on nature of science. Ideally, the professional development would include nature of science materials for the participants to integrate into already existing curriculum. This professional development would give teachers who currently do not include nature of science topics a direct path to do so.

Teacher preparation programs can support the inclusion of nature of science topics in general chemistry curriculum two different ways. The preparing institutions can provide support during pre-service education or as professional development opportunities for active teachers. Most teachers, 79%, are receiving some nature of science education in their pre-service methodology courses. These courses should develop an understanding of nature of science in the pre-service teachers and then support the future teachers in designing curriculum that includes nature of science topics. Teacher preparation programs can also facilitate workshops focused on nature of science.

At these workshops, current teachers can be provided specific activities and lessons that will integrate nature of science into existing curriculum.

The high percentage of standards being addressed in general chemistry classrooms, involvement in professional development, and the tendency to learn new pedagogical methods after the completion of a teacher preparation program, suggest that a few pointed, specific changes can successfully meet the needs of chemistry instructors. The participating teachers frequently made the request for pre-made lessons that integrated nature of science into the content they are already teaching. While these resources do not provide the perfect solution, it would be ideal if current instructors had the understanding, resources, and opportunities to integrate nature of science into their daily interactions with students, it is predicted that this would increase the frequency that students in Minnesota would engage with nature of science.

Content standards and nature of science standards should be explored and compared to the goal of science education. If the goal is to produce scientifically literate citizens there needs to be a greater focus on nature of science outcomes. Research suggests that nature of science topics lead to the types of critically thinking citizens that will reflect an engaged, scientifically literate population (Karakas, 2011; Tytler, 2007). If these are desirable outcomes for science education, it may be required to shift available classroom time from specific content standards to nature of science standards or to more effectively combine instruction that effectively combines both.

Science education methods courses were reported as including nature of science content by 79% of the participants. Comparatively, only 54% of participants reported that nature of science content was included in the science content courses completed in their teacher preparation programs. The results of this research suggest that more science content courses should explicitly teach nature of science content. Future science teachers, as well as scientists, would then learn a model for how to integrate science content with science as a way of knowing.

Future Research

The next step toward providing support for nature of science topics in current science curriculum is to identify what types of nature of science activities will successfully meet the state standards. Data must be collected to determine the types of content and activities teachers are willing to include in their curriculum. Mechanisms for a seamless inclusion of nature of science content will require that the lessons fit within existing coursework and minimally impact the amount of time allotted to a given unit or lesson.

A longitudinal study of how professional development regarding nature of science affects the practice of chemistry teachers would assist in determining what type of professional development leads to the most growth. It is clear that teachers continue to acquire skills and methodologies helpful for the instruction of nature of science after they leave their respective teacher preparation programs. An investigation focused on where and how they are learning the content that they are actually putting into practice would provide guidance for focusing all nature of science professional development. This type of study would provide reassurance that hours and resources spent on professional development is providing reliable and useful strategies for the inclusion of nature of science in their curriculum.

There is research demonstrating the importance of nature of science outcomes in science education (Karakas, 2011). It is not clear that these outcomes are strictly more important than chemistry content outcomes. Research comparing the outcomes of these two separate foci for science education programs will help inform the way that science standards are designed from the top down.

A qualitative study on the same research questions could provide insight that is not possible when using a survey as the primary research instrument. Interviewing chemistry teachers in order to learn about their own understanding of nature of science would help guide what professional development is most helpful. If teachers do not have a robust or complete understanding of nature of science, it is difficult to expect them to teach those concepts as part of their curriculum. Interviews provide a mechanism to collect this data without biasing the participants through multiple-choice questions. Participants could be asked open-ended questions such as “How do you define nature of science?” This technique would be especially helpful when identifying what pedagogical methods are used to teach nature of science. The survey used in this research focused on six pedagogical approaches chosen by the researcher. Through an interview, subjects could be probed about their understanding and meaning of the terminology they use for describing their teaching approaches and nature of science.

Summary

This research aimed to determine the frequency of nature of science standards being completed in Minnesota high school chemistry classes as well as what preparation Minnesota chemistry teachers received for teaching teacher nature of science. The data collected indicates that some nature of science standards are being addressed reliably (Table 5). Teachers bring varying levels of experience and confidence regarding nature of science with them into the classroom. Professional development is available for this topic and 71% of teachers have had the opportunity for at least some training. The results of this study demonstrated a reliable, positive correlation (.309, $p=0.027$) between engaging in the professional development and the tendency to include nature of science in a general chemistry class. It would be reasonable to predict an increase in nature of science content if the 29% of teachers that have not attended professional development on this topic have a chance to do so. There is a strong demand for focused, pre-made lessons and curriculum that would allow for teachers to include nature of science topics into their already existing curriculum. Teachers responded that they do not feel as though there is enough time to sufficiently address both the required content standards and nature of science standards in a general chemistry course. Further research on how this should be managed and prioritized could lead to meaningful reform for science education in Minnesota.

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Appendix

Responses to Survey Question: What is a roadblock you face to effectively teach nature of science in your classroom?

	Frequency
No Response	1
Background, student expectation, time	1
class time and class size	1
Curriculum already in place and used by the district. Material 'to be covered' and tested on is designated.	1
Curriculum focused on measured (i.e. tested) outcomes	1
Difficulty integrating into content, Run out of time	1
frustration on students' part	1
hitting all the other standards	1
I could use more support with my population.	1
I do not teach in Minnesota, so I need to follow through with other standards (IGCSE specifically) for instruction	1
I don't focus on it intensively because it is taught explicitly and abundantly in our 9th grade Science as a Way of Knowing Course.	1
It is inherently tough to learn thoroughly	1
It is my first year with this curriculum and haven't seen the goals and gaps yet.	1
It would be nice to have more background on the NOS	1
Lack of how to implement them through out and desire to do so	1
Lack of time	1
Limited time with many standards	1
n/a	1
Needing to teach other science standards pertaining to a specific content area (biology, chemistry, etc.)	1

Not enough time to get through all standards	1
Not enough time to investigate case studies involving bias, societal effects, pseudoscience	1
number of courses taught at a time-5 different contents including anatomy, physics, physical science, chemistry, biology	1
So many students in one class so the needed supplies used for investigation is high, websites to have a laid-out plan of how to teach them	1
Students ability to problem solve when not given exact directions. Thinking outside of the box.	1
students seem to want to just be told, not think about scientific problems solving on their own	1
The current media culture and the flaccid representation of science; including poorly written textbooks.	1
The following year students go back to learning "The scientific method" and not NOS.	1
There are so many targets to get to in the year that there is little time for expansion or addition of material.	1
time	4
Time	8
TIME	1
Time and other useless standards	1
Time constraints	1
Time, and adequate knowledge of how to engague students for the topic	1
Time, resources and class size.	1
time, training	1
Time, writing component	1
Time.	1

Too many standards	1
Too many standards. Is this one more valuable than content standards? Perhaps? Moreso than the content standards? Who's to say. I team teach so only have so much say and only have so much time each year.	1
Too much other curriculum to cover	1
where these standards should go; physcial science, biology, chemistry, etc	1
Total	52

Responses to Survey Question: What support or tools do you need to more effectively teach nature of science?

	Frequency
No Response	8
a clear understanding of what is expected from these standards and what grade level is most appropriate	1
A complete overhaul of the United Stated educational system. Not joking, I left teaching 18 mo. ago because what we call 'science' is high school is as far from scientific research as one can get (I have also been in research).	1
A dramatic reduction in the number of chemistry specific standards in the state standards, or an increase in required chemistry credit/instructional time in my district.	1
activities, etc already made for me to use.	1
Additional workshops and online tools	1
Better Curriculum that ties in NOS with other standards	1
Case studies, articles, to demonstrate bias, societal effects, pseudoscience. Need curriculum that addresses American Indian cultural methods of science, also other underrepresented groups including women	1
Example curriculum. Professional Development. Time to develop and implement	1

Fewer other standards	1
How about someone having specific examples of how to use them in class	1
I would love to team teach.	1
If I were to go back to MN to teach, I would need a bit of training as to what the new standards are and how they've been adapted and tested since I left	1
Less required content standards	1
Less specific standards regarding the other areas of science so more time can be used in a more student driven approach. We cannot do this in chemistry or biology currently because the content specific standards take too much time even with direct instruction.	1
lesson plans	1
lesson plans, assessments	1
Materials/Curriculum suggestions that insert it effectively	1
More awareness for teachers that have been teaching for a longer time	1
more direction from the standards as to when I actually have completed teaching =to what level to teach a standard	1
More emphasis in other science courses	1
More equipment, time, family support	1
More examples of lab based procedures that can be tied to other standard based requirements. Searching for lab matieral in order for students to "practice" the nature of science is time consuming. Often found labs online are very elementary OR very upper level.	1
more ideas	1
More resources and smaller class sizes.	1
More student background.	1
more supplies, more teachers in the room or fewer students, website of a laid-out plan to teach the benchmarks.	1
More than 1 semester to teach chemistry credit	1

More time	1
More time!	1
n/a	1
Needs to fit into the material I already cover	1
Professional Develepment slash paid work time	1
Provide lessons that show how to implement these standards in other lessons	1
Revlevant examples	1
Technology	1
time	1
Time	2
Time and access to a broader range of scientific literature.	1
Time and field trips	1
time, flexibility	1
video demonstration and inquiry activities	1
ways to incorporate the nature of science more effectively into existing lessons	1
We do most of the nature of science teaching in 9th grade physical acience. To do it at 11th grade i would remove act prep from my course and lighten the rigor of gen chem.	1
Total	52