The Qualitative Report

Volume 15 | Number 1 Article 6

1-1-2010

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Recommended APA Citation
Karakas, M. (2010). A Case of One Professor's Teaching and Use of Nature of Science in an Introductory Chemistry Course. *The Qualitative Report*, *15*(1), 94-121. https://doi.org/10.46743/2160-3715/2010.1142

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Abstract

In this article I provide a qualitative analysis of one faculty's teaching and answer the following research question: How does one chemistry professor who teaches introductory science incorporate aspects of the nature of science (NOS) into his course? This study concentrates on a single case in one private higher institution in the Northeastern United States. The participant's teaching style is presented through a combined presentation of interviews, classroom observations, and classroom activities. Six main themes emerged from the field notes in the areas of teacher actions, student teacher interactions, start of the lecture, incorporating NOS language in instruction, class size, and student actions These findings revealed that the participant preferred to use traditional teacher-centered lecturing as his teaching style; his main concerns were to cover more content, develop problem-solving skills of his students, and teach fundamental principles of chemistry without paying special importance to the aspects of NOS.

Keywords

Nature of Science, Case Study, College Science Teaching, and Higher Education

The Qualitative Report Volume 15 Number 1 January 2010 94-121
http://www.nova.edu/ssss/QR/QR15-1/karakas.pdf

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In this article I provide a qualitative analysis of one faculty's teaching and answer the following research question: How does one chemistry professor who teaches introductory science incorporate aspects of the nature of science (NOS) into his course? This study concentrates on a single case in one private higher institution in the Northeastern United States. The participant's teaching style is presented through a combined presentation of interviews, classroom observations, and classroom activities. Six main themes emerged from the field notes in the areas of teacher actions, student teacher interactions, start of the lecture, incorporating NOS language in instruction, class size, and student actions These findings revealed that the participant preferred to use traditional teacher-centered lecturing as his teaching style; his main concerns were to cover more content, develop problem-solving skills of his students, and teach fundamental principles of chemistry without paying special importance to the aspects of NOS. *Key Words: Nature of Science, Case Study, College Science Teaching, and Higher Education*

Introduction

The long history of advocacy for teaching about nature of science (NOS) in science classrooms is evidenced by the National Society for the Study of Education (1960) and Hurd (1960) who claim the existence of this goal in United States schools as early as 1920. Currently, the National Research Council (NRC) clearly states the most recent objectives of science education with the following statement:

> Science is a way of knowing that is characterized by empirical criteria, logical argument, and skeptical review. Students should develop an understanding of what science is, what science is not, what science can and cannot do, and how science contributes to culture. (NRC, 1996, p. 21)

Additionally, the American Association for the Advancement of Science (AAAS) further supports the advocacy for teaching about NOS with the following statement:

> Education in science is more than the transmission of factual information: it must provide students with a knowledge base that enables them to educate themselves about the scientific and technological issues of their times; it must provide students with an understanding of the nature of science and its place in society; and it must provide them with an understanding of the methods and processes of scientific inquiry. (AAAS, 1989, p. xii)

Most recently NOS has been included as a critical component of scientific literacy (AAAS, 1989; NRC, 1996; National Science Teachers Association (NSTA), 1982). Understanding of NOS is considered to be a significant component of scientific literacy given the basic assumption that an understanding of NOS will enable students, and the general public, to be more informed consumers of science so that they can make informed decisions when confronted with scientific issues. In order for someone to acquire scientific literacy, it is important for that individual to understand how scientific knowledge is generated. However, in order for science teachers to teach about NOS, they need instruction that explicitly addresses the history, philosophy, and the workings of science not only in their pre-service science methods courses, but also in their undergraduate science courses.

The nature of science has been defined in many ways in science education literature. In spite of the significant progress toward characterizing science there is no single definition of NOS that fully describes all scientific knowledge and enterprises (Schwartz & Lederman, 2002) and there is always likely to be an active debate at the philosophical level about NOS (McComas, 1998). However, at the level of helping individuals understand the basics of science in order to promote an effective science literacy, there is a general agreement about the aspects of NOS among science educators that scientific knowledge is tentative (subject to change), empirically based (based on and/or derived from observations of the natural world), subjective (theory-laden), partly the product of human inference, imagination, and creativity (involves the invention of explanation), and socially and culturally embedded. Two additional important aspects are the distinction between observations and inferences, and the functions of and relationships between scientific theories and laws (Lederman, Abd-El-Khalick, & Akerson, 2000).

Moreover, new reform efforts also place a strong emphasis on the need for teaching for understanding in which students can make sense of key science concepts, construct their own knowledge, and see connections between what they learn in school and everyday life (NRC, 1996). The new standards on teaching for understanding call for teachers to make thoughtful selections of curriculum content, be clearer about their purposes and goals, and make assessment embedded in performance that is more integral to teaching and learning (NRC). Superficial coverage of overly broad content and multiple-choice tests that feature recall of information are no longer recommended (Wiske, 1998). More thorough inquiry is recommended around a smaller number of critical ideas, concepts, and themes that are studied in depth, returned to at different grade levels, and connected both to ideas across various fields of inquiry and to students' personal lives (NRC; Uludag, 2005; Wiske).

Clearly, science educators (e.g., Abd-El-Khalick & Lederman, 2000; Duschl, 1985; Lederman, 1992; Wiske, 1998) and scientists have been persistent in their advocacy for improved student understanding of NOS and teaching for understanding in American schools over the past several decades. The development of an "adequate understanding of the nature of science" (Lederman, 1992, p. 331) or an understanding of "science as a way of knowing" (p. 331) continues to be convincingly advocated as a desired outcome of science instruction.

In line with this advocacy, in the present study I investigated how one chemistry faculty teaches, understands, and communicates NOS to his students. This information will help science educators to better understand the use of NOS instances and particularly the incorporation of history, philosophy, and sociology of science into introductory chemistry courses. Incorporating instances of history and philosophy of science in introductory science courses is important, because as Klopfer and Cooley (1963) found in their early study, the use of materials derived from the history of science could help to convey important ideas about science and scientists to students.

Methods and Participants

Introduction

In this study I provide qualitative analysis of data in order to explore how one faculty teaches chemistry and NOS. I answer the following research question: How does one chemistry faculty teach about science and incorporate aspects of the history of science into his introductory course? I concentrated on one case, Jack (name is a pseudonym) who was chosen as a case study participant to explore in greater detail what occurs inside an introductory level chemistry course in one particular private higher educational institution in the Northeastern United States. A case study is expected "to catch the complexities and particularities of a single case… we study a case when it itself is of very special interest, we look for the detail of interaction with its context" (Stake, 1995, p. xi). Results are presented through a combined and detailed presentation of the participant's interviews and classroom observations supported with examples from his classroom activities. This study was a part of a bigger study that I conducted (Karakas, 2008). Jack's case was pulled out and presented here separately in greater detail, because of his traditional views on NOS and his traditional teacher-centered teaching, and because a lot of data and quotations were left out in the bigger study that truly portray what occurs in an introductory chemistry course (the larger study concentrated on all introductory science courses). Institutional permissions (IRB) were obtained from Syracuse University and from Jack's university. Jack gave his consent to participate in the study.

Data collection

I observed Jack during the spring semester of 2005. He was teaching an introductory level general chemistry course for science majors. I observed him in 23 of his 28 class sessions. The ones that I did not observe were either midterm or final exams or review sessions for the exams. There were two sessions of this course each week, one on Tuesday, and one on Thursday from 12:30 pm until 1:50 pm. I took notes during the lecture and later on transcribed them to a Microsoft Word document. I tried to sit in different places during all observations, so that I would have different views of the classroom activities. This course also had a lab attached to it, but four graduate Teaching Assistants taught the lab. I did not observe these labs. The setting was a large auditorium with two aisles dividing the 300 seats.

Interviews

I conducted one in-depth individual interview with Jack prior to the observations in the spring semester of 2005 in order to explicate his understanding of NOS. The interview time was 1 hour and 30 minutes. The interview was conducted in person in Jack's office. I chose Jack for lecture observations according to his understanding of NOS and his willingness to participate in further research.

In the present study I used a loosely structured interview guide (see Appendix A), as recommended by Bogdan and Biklen (1998), in order to "get the subjects to freely express their thoughts around particular topics" (p. 3). In this study the topic was an understanding of NOS. Loosely structured interview questions were developed by the researcher with the help of some qualitative researchers over the period of a year. Initial development of the questions occurred during a research apprenticeship project in one qualitative research methods class in which I investigated six scientists' views on NOS by looking at various survey instruments measuring students' and teachers' understandings of NOS, by consulting with the instructor of the methods class, and by finding and adding additional questions after each interview. Thus, the development of the questions was evolutionary in nature. They evolved over time and entailed a literature review. Interviews were recorded on a digital voice recorded and later on transferred to a PC computer.

I conducted a follow-up interview with Jack in the fall of 2005 in order to further explicate his understandings of NOS and to obtain his rationale for using or not using NOS in his instruction. This follow-up interview deliberately covered aspects of NOS and teaching practices identified from the analysis of the field notes and initial interview transcript. Before I asked a follow-up question I would explain what I had observed to Jack and then ask him a question (see Appendix B).

Observations

Observing in a setting requires good listening skills and careful attention to every detail, both visual and non-visual (Creswell, 2002). It also requires dealing with issues such as the potential deception by participants being observed and the initial awkwardness of being an outsider without initial personal support in a setting (Hammersley & Atkinson, 1995). Thus, I tried to blend in more easily with the students by wearing jeans and sweatshirts, and by sitting in different places during the lectures. I took complete records of chalkboard notes if there were any. I obtained class handouts, assignments, and noted the physical environment of the class. I kept notes on teacher mannerisms and nonverbal cues during the lecture (Zeidler & Lederman, 1989). For example, I wrote down whether Jack was moving around the classroom and making eye contact with students with an aim to see student-teacher interactions. I also took notes of the activities that occurred during an entire class session in each of the 23 observed lectures. With each observation, my way of taking notes changed. At the beginning of the observations I tried to write down everything Jack wrote on a board or on an overhead slide, but later I started to look for more specific interactions between Jack and the students, and among students themselves. Thus, note taking during the observations was evolutionary in nature. The general purpose of classroom observations was to generate a picture of what the instructor and the students did during a given lecture.

Data Analysis

Theoretical lens

I used a realist mode in this study to represent Jack's perspectives through closely edited quotations and interpretations of those quotations (Creswell, 2002; Van Maanen, 1988). Thus, I neither claim to arbitrate nor to assess the right answers about NOS, but rather, I let the participant share his thoughts on NOS and compare these thoughts with the current science education literature. On the other hand, I share Roth and Lucas' (1997) view that informants' talk about attitudes and beliefs are dependent on context and are highly variable within a given individual. Rather than reflecting on individual beliefs, informants' "talk reflects the communities and language games in which they participate, for there are no private languages" (p. 147). Therefore, I make no claims that the data gathered represent an informant's permanent and deep-seated views; I read them as socially constructed in the moment. Furthermore, while the qualitative researcher intends to tell a story from the view of the participant, he or she can never divorce the words of the participant from his or her interpretations of them and therefore, my "biography, politics, and relationships become part of the fabric of the field" (Bell, 1993, p. 41). Although I lead the reader toward meaning from the participant's quotations, I tried to put as many quotations from Jack as possible for every emerging theme and sub-theme, so that the reader can form his or her own meanings from those quotations and read them from his/her own background, because they may be different from my views. I am a researcher from Turkey and taught in elementary and middle schools, and in college in Turkey. I was taught in ways that portrayed science as a fixed body of knowledge. Therefore, my educational and social location might have played a central role in the analysis and interpretation of the data.

Analysis of interviews and field notes

I used constant comparative approach (Glaser, 1992) in organizing and analyzing the data. This method results in saturation of categories and emergence of theory. Theory emerges through continual analysis and doubling back for more collection of data and coding (Bogdan & Biklen, 1998; Glaser). Thus, continuous data analysis was performed as information was collected during the study. The first step taken in the analysis of the data was data organization procedures recommended by Bogdan and Biklen. Initially, categories defined by the theoretical framework (the seven aspects of NOS defined in introduction) were followed, but as more data were collected, new categories that emerged were defined and old ones were redefined. First-interview, classroom observations, and follow-up interview were coded and analyzed separately. First-interview data were coded according to the participant's views on NOS and later on, repeated themes were grouped into coding categories. For example, initially I read statements and identified these themes as science is universal, art in science, science and religion, science is experimental and later grouped them into one of the NOS aspects as categories such as, tentative NOS, empirical NOS, subjective NOS, creative NOS, socio-cultural NOS. Final categories that emerged from the first interviews were as follows; Definition of Science, Subjective NOS, Empirical NOS, Tentative NOS, Creative NOS, Social and Cultural NOS, Theory and Law in Science, Difference between Observation and Inference in Science. I wrote the field notes immediately following each classroom observation, and later coded and grouped them according to emerging themes. I coded each set of 23 observation notes separately and more than 20 codes emerged for each field note. Repeating themes in these field notes such as, eating food, playing with cell phones, and solving puzzles emerged and they were grouped into one category and named class distractions. Later this category was merged into the Student Actions theme. Six main themes emerged from the field notes and they were Class Size, Teaching Approach, Student-Teacher Interactions, Start of the Lecture, Incorporating NOS Language in Instruction, and Student Actions. Various codes emerged from the follow-up interview too. Codes, such as use of history of science, use of NOS language, students' distractions and disinterest with a lecture, and use of question and answer (Q&A) these codes were merged into an instructional strategies and problems theme. The themes that emerged from the follow-up interviews were as follows; Class Size Effect, Instructional Strategies and Problems, and Suggestions and Qualifications to Teach Introductory Classes. Several analytical memos were written for Jack's teaching style during the observations. Teaching style was described by looking at Jack's interaction with the students and whether his teaching was student-centered or teacher-centered, or whether he used group work in instruction.

Researcher context

I am a researcher from Turkey. I entered this research project interested in questions that explored teaching NOS in science classrooms. That interest started in one of my first science methods classes. I read an article by Clough (2000) who made a great point that we should teach the rules of the game (in this instance the rules of doing science) before we start teaching science. This point made great sense to me, because I experienced this kind of problem when I first came to the United States. I was not able to enjoy the fun of U.S. football and baseball, because I was not aware of the rules, so I wondered what they found interesting in these seemingly boring games. Now that I have learned a little bit about the rules of U.S. football, I can enjoy some of the fun of this game, but I still do not know the rules of baseball and I am still bored by it. My point is that if we, as educators, do not teach our students about NOS (the rules of the game) we cannot expect them to enjoy doing and studying science and take pleasure in what they are doing in science classrooms. That is how I became interested in this topic and why I explored it by narrowing its focus on an introductory chemistry course and a professor who taught it.

Next, the results will be presented by giving a brief introduction to Jack's background, then presenting data from his first interview, later presenting data from his classroom observations, and finally by presenting data from his follow-up interview.

Jack's case

Jack grew up in southeastern U.S. and went to public schools there. He was an undergraduate at highly-ranked research university in the Midwest and earned his Ph.D. from another university in that region. Jack did not do a post doctorate and has been teaching introductory chemistry courses for 19 years in this private research university, but his main focus was on his research. Jack lived with a foster family, who supported him throughout his education, but did not guide him in becoming a scientist. His first interest in science started in middle school as a self-interest and parental motivation (his foster father was working in Boeing engine factory and he was bringing model airplanes to the house that got Jack interested in science). Jack likes to read history books and professional journals. He follows the creationism versus evolution debate, abortion debate, the cloning controversy, and he is interested in the role of the university in science, commerce, and intellectual rights debates. Jack described the best science teachers as those who were enthusiastic, encouraging, entertaining, funny, and ones who "explain things in a plain way." Jack said nothing in his education was designed to help him understand how science works. He chose chemistry because it is a central science:

> I – So why chemistry, like why did you choose … (Interruption by the interviewee)?
>
> Jack – Oh I can tell you exactly why I chose chemistry, because when I took biology I wanted to be a biologist, when I took chemistry I wanted to be a chemist, when I took physics I wanted to be a physicist, when I took math…. …I chose chemistry for one reason: it is the central science. I can do all of science if I do chemistry. I can branch out to anything I want if I do chemistry. …I already published in physics journals. I published in biological journals. I published in chemistry journals. It gives me the broadest range of things that I can think about in a serious way and maybe actually do something about it and that is…chemistry. I literally live where the objective view of the world is.

Interviews

Definition of Science

The first interview analysis of Jack revealed his views on NOS. Jack believed that "Science is this: It goes directly to the question of what are the things that you can directly verify by experiment, by checking it out, by observation, and anything that doesn't go in that is not science. Now there are some things, historical things, we can't go back and retell which year Haley's comet came in, but a lot of people saw it. In certain cases there are issues of historical observation that you can accept as a science. For example, sun spots. The Chinese have been keeping records of sun spots for thousands of years, I believe their numbers. On the other hand, anything else, if it cannot be tested and re-observed, and can't be tested by someone else, is not science, period, that is all there is to it. All of religion is that way; anything you must take on faith is religion or something else, but it is not science. I teach that in class … and the very important aspect in the whole course is to know the difference between science and everything else, because that is the difference between objectivity and subjectivity." This statement shows Jack's views on the empirical and objective nature of science.

Subjective NOS

Jack expressed the view that science is not subjective and that a "scientific type of person" must be "objective, must trust the numbers, and that most scientists are capable of separating their professional and non-professional life." However, the following excerpt shows his varying views on this NOS aspect, where he points that scientists bring their background in when solving some problems and have different ways of looking at things:

> I – So, do you think that there is a one kind of scientific method that all scientists follow or that each one has his/her way of doing?
>
> Jack – Well, you know it is funny you should put it that way. I think that there is. First of all people do not think the same way.... Ah, it is like this; I had a model for a certain kind of phenomenon several years

> ago and at that time I really liked it, I thought it was really interesting. And so I kept seeing ways of applying it in different kinds of problems and one of my best friends said, 'Jack you are like the guy who invented the hammer.' After that everything was like a nail, because you want to keep trying. If you had some things accepted you want to find ways of applying it and getting something out of it for a lot of reasons, some of which are just purely impractical. I want to get as much mileage as out of some work I already have done. On the other hand, in terms of whether the people think the same way, they do not think the same way, because some people will tend to be analytical, and some people will tend to be mathematical, and some people will tend to answer some other way, all different kinds of approaches that people would apply depending on the problem. That is why some people solve certain types of problem better than the other guy does. And the other guy solves this other kind of problem better than the first guy does, because they have their own ways of apprehending it and they don't change that rapidly. I believe Chandrasekhar changed problems about every ten years, because he recognized that. …. I don't know if it applies to me or you or anyone else, but it worked for him. So you try to do something else. After that you find a different battle to fight, if you will. People have different ways of thinking about these things. And so if you really want to know a complete mind set change, I mean, I did this myself recently. I have always done very physical things--molecular beams and vacuum changes. And in the last five years, I have done things, biomedical things, which bring a whole different load of concepts… It was really refreshing, I had to work muscles, … so it was a very good thing, but it makes me think that people don't think the same way, because everybody is at different stage at different times depending on their age and then in their career and what they like and what they don't like at the time. The times call for different things. There was a time when certain things were required then. Now everything is hot and you had to adjust to the time.

Empirical NOS

Jack explained his views on the empirical and experimental nature of science as follows:

> I – So, How do you know that something is science or scientific?
>
> Jack – How do I know if something is scientific, because I can look at it and I can say 'Oh, I can check that,' and I don't need to have anybody there. There is a classic case, in this bottle (showing his two liter soda bottle he was drinking from while talking); a person sets another person trying to get them to invest in it. And they say inside this bottle there were more positive charges than negative charges, so that this was charged on the inside. After I stop laughing, I say well I am a good scientist, tell you what, before I tell my friends to invest or not to invest, I'll check it out. And I said, all right, if there are more protons in there then it should create static charge, just like static

> electricity, and so I should be able to discharge an electrometer on it. …It doesn't do any of those things; therefore if it has an unbalanced charge it is very little, it is insignificant and it doesn't matter and don't invest. And so the way you can tell if something is science or scientific or not is the ability to do reproducible tests on it, that anyone can do with the right equipment and that will result in reproducible observation.
>
> I – How do you see scientists do science?
>
> Jack – How do I see scientists do science? Just the way I said. If they don't do it that way then they are not a scientist. I don't care what they call themselves, because that is what science is. The very nature of science … is the ability to have something be reproducible. It is like Missouri, did you ever see the license plate from Missouri, it is the 'Show Me' state. They don't believe in anything unless you can show them, show me that it works, show me that it is what it is supposed to be, show me that if it is true. Then laws of physics tell me that if A is true then B must be the true answer. I am going to check B and C, I am going to make sure before I believe that A is true and I am going to do it that way. And nothing else is going to convince me of anything, no amount of wanting it to be true will make it true. The only way that makes it true is pure physical reality.

These excerpts clearly show Jack's deep belief in empirical and reproducible NOS.

Tentative NOS

Jack had mixed views on the tentative nature of science. Here is an excerpt:

> I – So do you think that science is tentative and that science is changeable?
>
> Jack – Absolutely not, it is exactly what it is, what has always been, and it will never be anything else and it doesn't matter whether it is here or on Mars or the surface of Titan, right? When they built a device in this world and sent it to Mars, it works the same way in Mars as it works here. The laws of science, the laws of physics are the same everywhere and that is the way it should be, it is not a question of how it should be, that is the way it is. I keep an open mind; if something is worth the change, I will be willing to say 'OK, maybe there is something different about Mars,' this device works inaccurately, so I would consider possibility of equipment malfunction, but I would always keep an open mind. You have to keep an open mind. That is one of the most important things about science. Even for things like the conservation of mass, the conservation of energy. It is going to be hard to convince me, but in the end … without even checking I won't say no. I will just say not likely that you are going to convince me. Would you like to make a bet of money first, so that I can take your money?

Creative NOS

Jack believed science "absolutely, absolutely positively" involves imagination and re-quoted Nabokov "there is no science without fancy, there is no art without facts." He said:

> When you actually do science you have to keep an open mind and you have to extend the scope of your view or contract it depending on what you are trying to do, and how well you are understanding it and how well your hypotheses are working. If they are not working, well then you sat back and think some more.

Jack also thought that there was a lot of creativity involved in choosing which questions to answer and how to design an experiment. He gave an example from his field that portrays the "art at the beginning of doing certain kinds of experiments":

> At the very beginning of doing certain kinds of experiments, there is usually what we call art at the beginning. Because nobody knows what is important, nobody knows what all the factors that influence the outcome of an experiment are. And at the beginning …you just need to know what matters. There are, and I am sure there will continue to be into the future as people do more and more experiments in different ways, at the beginning there would be what we call art. There is a kind of experiment that people do in spectroscopy, a thing called novel beam…Well, the operation uses beams. When I was a graduate student, and to this day really people call and they say 'well, how do you get the coldest beams and how do you get to do this?' You don't exactly understand it, but everybody knows what to do. And you can see that it is written in the literature and what it amounts to is a description: 'do it this way, the hole should be this size, you drill the hole this way.' And if you do it that way you get the right answer, you get reproducible results. That is why we publish. And then we can argue what it means and all that, and we can argue later about why you have to do it that way.

Social and cultural NOS

Jack believed that the pressure of funding determines what science is done and thought that scientists bring their cultural background in their research "only in their explanations when they talk to people and try to get money, and try to get acceptance," because he thought "in a capitalist society you don't make any money unless you sell something, you don't generate the capacity to do more science until you sell something and give people benefit for what they do." He continued:

> So when you do sales, you look at the customer, the person who is buying and you explain in terms that they understand it and they appreciate it. And if you don't, they won't come and do what you want them to do. And so most people are not actually telling what they want. They are telling what, if they are successful, they are telling what the

> other guy wants to hear. And they have to, because that is what works. Generally speaking that is sales.

Theory and law in science

Jack believed theory and laws in science are "completely different things." He said "theory is just someone's explanation for why a certain part of the physical world is the way it is, or just a description within some theoretical framework." Law on the other hand, "the truly scientific law is immediately grounded in the empirical." Jack explained "theory is just like these religious laws and human laws, they come and go like air, like wind." He gave the following examples for what scientific laws are:

> Newton's laws of motion really, thermodynamics for sure, the three laws, those things are actually just statements of empirical facts. We needed worth to make those statements and so one might think that those things have something to do with a theory. In actual fact they don't, all they are is just a statement of an empirical fact and it tells you how to define that fact, so that you can measure it, see it, show it, it is never ever violated. And so, you can choose different words, you can choose a different paradigm in which to state these facts, but they still would be the same basic empirical facts, you would do the same basic experiment to test them. And then you would find that they are never broken. So, the words you chose, the situation, the paradigm that is a theory that can change, like I said like the wind, but the empirical facts that is a law definitely.

Jack did not think "so much" that "theory turns into law," he clarified, "what happens is that theory gets to a point where it allows us to restate the same empirical truths that we had before, but in a different paradigm so that it seems to contain a greater understanding of the world around us, but they are still the same laws, they are ultimately the same laws." Later on in his interview he gave the definition of the distinction between theory and law in science, as recommended by science education literature, he said "I guess I would like to think that law has something more to do with the way the world really is and theory has more to do with the way we look at it."

Difference between observation and inference in science

On the difference between observation and inference in science Jack stated that "an inference is not necessarily reproducible, but you can do the same experiment twice get exactly the reproducible results and show it to two different people and get two different sets of inferences with the same exact set of facts, so observations are fully reproducible, inferences are not necessarily," and "observation is a statement of the empirical truth." Here is an excerpt from his interview that portrays these views:

> I - How are inferences and observations in science different and how are they similar?
>
> Jack – Well, observation is a statement of the empirical truth. I look at this and it was there, I looked at it, I measured it. It was this big, it was

> that big …and that is unconvertible as long as you are talking about honest people. Inference on the other hand …that is a completely different thing that is a step into the unknown that requires more observations and more experiments to manipulate the situation, so it is to see what actually occurs. But now you entered the realm of trying to divide the paradigm …but the observation is exactly what it is. Another way of putting this in a similar context is what we said before, that an inference is not necessarily reproducible, but you can do the same experiment twice, get exactly the reproducible results, and show it to two different people and get two different sets of inferences with the same exact set of facts. So, observations are fully reproducible, inferences are not necessarily. Does that help?

Summary

These views reveal that Jack had complex and mixed views on the NOS aspects. His views were modernist in some aspects and traditionalist in others aspects. He believed that science is an empirical and creative endeavor, that theories and laws in science are different and there is no hierarchical relationship between them, and clearly distinguished between observation and inference in science. Jack also believed that science is socially and culturally embedded. However, he tended to view science as absolute and objective body of knowledge and did not give credit to the theory-laden and subjective nature of science.

Observations

Class size

The class size was quite large with the average around 150. In the beginning of the semester there was around 200-250 students inside the auditorium, but at the end of the semester the class size dropped dramatically, sometimes to 60-70 students; the female-male ratio was in favor of females and there were very few minority students. Maybe 30 out of 150 students comprised the minority population. The big class size affected the teacher-student interactions. For example, there were times that the teacher did not see students who held their hands up, and therefore missed the opportunity to interact with them or did not see students who were reading magazines and newspapers, sleeping, and talking among themselves.

Teaching approach

Jack's instruction was a traditional, teacher-centered lecture, in which he used a lot of complex chemical language, or a lot of math and chemical formulas in his explanations with little indication of their meaning. Below is an example:

> Instructor: this is the first time when people were able to calculate A and B molecules
>
> *He gave the name of a Nobel Prize winning chemist in 1986 who was able to do that*

Instructor: I will go slowly, any questions?

No one asked any questions. He repeated himself again and still no questions

Instructor: Just say yes. I feel better every now and then if you just answer yes.

Then he started writing on the overhead projector again.

Instructor writes: Rate Law = Expression showing how the rate depends on the concentration of reactants

$A + B \rightarrow C$
$D \rightarrow E + F$

Instructor: If we know rate law for a reaction and its rate for a set of reactant concentrations we can calculate K (rate constant).

He wrote another example for how to calculate the rate constant. A female asked a question about his writing. Then he wrote:

With the rate law in hand <u>AND</u> if we know the value of K => we can calculate the rate of reaction for any set of concentrations.

Two female students behind and four seats left of me were giggling. The teacher continued writing:

Reaction Order:

General form of a rate law is:

$$\text{Rate} = K\ \{\text{Reactant1}\}^{m} \times \{\text{Reactant2}\}^{n}$$

The exponents m and n are called "reaction orders" overall reaction order is the sum of the orders of all the reactants => m + n

$$\text{Rate} = K\{NH\}^{+1} \times \{NO_2\}^{+1}$$
Overall order = 1 + 1 = 2

Two females held their hands up the instructor did not see them he was busy writing example on the overhead projector. A male student sitting next to me wasn't taking any notes. He looked like he did not understand what the teacher was talking about, however he was sitting quietly. One female student left the class. The teacher was still busy writing on the projector and giving more examples for overall order calculations. Most of the students in the auditorium looked out of touch with what the instructor was talking about. He wrote:

* NOT: You can have reaction orders that are fractional or even negative.

> *A male held his hand up and two more students left the class. The teacher did not see the hand again; he was still busy writing his examples on the overhead projector. Another female held her hand up, this time the teacher did see the hand and answered, the question was about what he will include in the exam. He wrote a chemical equation on the projector it was as follows:*
>
> $CHCl_{3\,(g)} + Cl_{2\,(g)} \rightarrow CCl_{4\,(g)} + HCl_{(g)}$
>
> Instructor: This is a very important reaction. It is what happens with the Ozone Layer. That is how we reduce the Ozone Layer and wrote:
>
> Values of the exponents are determined experimentally. Units of the Rate constant depend on the overall reaction order of the rate law.
>
> Instructor: Let's see what we were talking about. He wrote:
>
> Unit of Rate = (units of the rate constants) x (units of the concentrations) – overall order
>
> Units of the rate constant = unit of rate / (unit of concentrations)^2 = M/S / M2 = M-1S-1
>
> This would be different for 1st overall, 3rd overall etc. (Observation # 2, January 20, 2005)

He always stayed in front of the overhead projector, which is in front of the auditorium, and did not move at all around the auditorium. Jack wrote his explanations on the overhead projector and from time-to-time looked at the students in the front rows and explained a concept or solved a problem in all of the observations I made. Jack's main activity during the lectures concentrated on problem solving; he would introduce a new concept, talk about it, and start solving problems related to that concept. Jack hardly showed any signs of enthusiasm about his subject and spoke in a monotone voice during the entire semester.

Student-teacher interactions

Jack made eye contact only with the students sitting in the front rows and they listened to him attentively. But the students in the back rows after a while usually lost interest with the lecture and started to show signs of disinterest and boredom by talking among themselves in groups of two or three in low voices, some just looking disinterested with the lecture, some reading the school newspaper or solving a puzzle in it, some playing with their cell phones, some reading a novel or a magazine, some solving math problems for another class, some eating food in class, and some just sleeping. There was a lot of eating going on in this class, the class period was scheduled for lunch time, and so some students were bringing lunch and eating in class. This eating prevented them from concentrating on the lecture, because some students would see other students eating and they would go out during the lecture and get food from the vending machines and start eating too. Students had easy access to the school newspaper; it was almost in every building around the campus and it was complimentary, so students were bringing it to the classes. Below is an example from an observation excerpt:

> *The instructor started the lecture by talking about the upcoming exam. Some students were still talking loudly. Few students asked questions about the exam and he answered.*
>
> Instructor: Does anyone have any questions about anything?
>
> *There was no response from the students and the teacher started summarizing what they did last time. Some students were still talking quietly and a few were eating their lunch. Students in front rows were listening and taking notes, while some students in back rows were talking in low voices and some were reading the school newspaper. An Asian male and two Asian female students in front of me were talking in low voices among themselves. The teacher was still summarizing the equilibrium concept. Students were now overall quiet. White male and female students in front of me were reading the school newspaper. The two Asian females in front of me each opened a magazine and started looking at them. At 12:45 pm. the teacher started the new lecture of calculating equilibrium concentrations, and started solving a chemical equilibrium problem. Students were overall quiet, but I could hear some students talking in low voices in back rows. I saw one female in the front row, sitting next to the wall, reading the school newspaper. Some students in the back were talking in a little bit louder voice now. The teacher was writing on the projector and solving the equilibrium problem and explaining at the same time. The teacher started solving another equilibrium problem. Students were quiet and some taking notes. Asian females in front of me were still looking at their magazines. Some students in the back rows were still talking in very low voices. The teacher asked a few questions to students while solving the problem to involve students in the lecture. The Asian female in front of me was reading Glamour magazine. Students became very quiet. The instructor was still solving the problem by writing on the projector and explaining at the same time. A White male left at 12:59 pm. and returned after a while. Some students in back started talking again in very low voices. Students in front rows were listening attentively to the teacher and taking notes. Teacher finished solving the problem and gave a quadratic equation formula by writing it on the projector and gave an example for a quadratic equation formula. Teacher started solving another example problem for chemical equilibrium concept by using the quadratic formula to solve it this time. The two Asian females in front of me were still looking at their magazines. The teacher was solving the problem by writing on the projector and explaining at the same time.*
>
> Instructor: Do practice to get good at handling the numbers (talking about the importance of numbers when solving an equilibrium problem at 13:13 pm).

A White female in back of me was playing with her cell phone.

Instructor: These problems are not that hard, you just have to be careful. They are particularly not hard if you practice a lot.

He started solving another example problem at 13:17 pm. Students overall were quiet with some students in back talking in low voices. Asian females in front of me were still reading their magazines. I saw three students sleeping on my right. The other Asian female in front of me was reading a Cosmopolitan magazine. The same White male, who left before, left again at 13:25 pm. Someone from the back rows left too. I heard the back door opening and closing. An African American female student left through the front door. One of the Asian females in front of me stopped reading her magazine and opened her cell phone to play with it. White female from the front rows left from the middle door. The African American female returned after a minute. The White female returned after a minute too. The teacher started explaining new concept of quantitative spectroscopy by writing on the projector and talking at the same time. The Asian female in front of me was still playing with her cell phone and the other Asian female was reading her Glamour magazine. Asian male sitting next to her was taking notes during the entire lecture. Students were overall quiet. Teacher was explaining the absorption concept. A female asked a question about the teacher's hand writing, he explained. White female in back of me was sleeping with her head leaning on the back seat. The teacher was explaining the new concept by drawing graphic pictures on the projector. Students were quiet. White female in one of the front rows was playing with her hair. White male next to me was playing with his cell phone. Teacher was showing spectroscopic graphics on the projector and explaining them.

Instructor: Does anyone have any questions?

No response from the students. Students started preparing to leave

Instructor: I will see you all next Tuesday.

Students started leaving the class. Few students talked with the teacher in front of his desk. (Observation #13, March 3, 2005)

Jack incorporated, in few lectures, a question-answer type teaching strategy, in which students asked questions about his explanations to a concept or his handwriting, because he had illegible handwriting so the students had a hard time reading what he wrote on the overhead projector's slide. During the semester, several times, Jack emphasized the importance of units, numbers, and mathematics in science and said "practice makes it perfect," meaning solving a lot of problems will make students good at numbers and units. He realized on a few occasions that students became bored with the lecture and used some humor to make the instruction a little bit more interesting. In another lecture he made students do some physical exercise or talked about spring break stories to make students active listeners again, but the teacher's attempts were mostly unsuccessful.

Start of the lecture

Jack usually opened up his lectures with some relaxing talk about recent events in the media, such as the Super Bowl, or made some jokes to warm up the class. He always asked students whether they had any questions about anything at all in the beginning of the lecture. Usually students asked questions about the procedures of an upcoming exam. In a few lectures he made a few announcements about the upcoming exams. Jack usually started the lecture with a summary of the last lecture. Several times during the semester Jack had some classroom management problems at the beginning of the lecture; students were generally very noisy at the beginning, and Jack had a hard time quieting them. He spoke in a louder voice and pleaded with students to get them quiet. The atmosphere of the class before the lecture can be inferred from the following observation excerpt:

> *It was a cold winter day in February, around 25 F degrees. Outside there was light snow falling and there were 5 inches of snow on the ground that had fallen during the night. I arrived at 12:20 pm. There were few students in the class, around 40 students out of 250 enrolled. Students were entering a few at a time, some sitting in front rows and some in back rows. I sat on right, seventh front row next to the wall in the auditorium. There were a few students reading newspapers in front rows. Students were talking among themselves and students in back rows were talking louder than front row students. Students were now coming in steadily. The teacher came at 12:30 pm and put his bags on the front desk. Teacher put the overhead projector on the front table and prepared it for class. The first two blinds were closed already. Students were talking loudly and a few more were coming still, some were leaving. The instructor was preparing his notes. Few students in front rows were still reading the school newspaper. Students were still talking loudly among themselves.*
>
> Instructor: Hello, how are we doing? It is no Miami Beach out there I can tell you that (he reminded students that they have an exam next week). Any questions about anything?
>
> *Students got quiet now and a female asked a question about the seating in the exam and the instructor answered her. A male asked a question about whether he will do a review section at all. The teacher said that he did not plan for that, but he will give them a practice exam today and will answer it next Tuesday, which is the class before the exam.*
>
> Instructor: Are we good? Any other question of any kind? (There were no questions asked). Patriots were good. Next year the Dolphins, my team, will do better than this year.

The teacher opened up the lecture with a current event, which was the Super Bowl played on Sunday night, to get students attention and started the lecture. (Observation #8, February 10, 2005)

Incorporating NOS language in instruction

Jack hardly used any NOS language in his instruction, although in two or three lectures, he used some history of science in his instruction by giving background information about the development of the equilibrium concept or the life of a scientist, such as Newton. Here are some excerpts from the field notes:

Jack started to explain a new theory from chapter 14.5 on the book. The theory was temperature half rate collision theory or more known as transition state theory. He then explained that this theory started in the 1950s and gave a brief history of how this theory developed. (Observation # 3, January 25, 2005)

Jack gave some example from the history of science. He said:

Arrhenius did his equation as a dissertation and got the lowest possible grade for it and 15 years later he got the Nobel Prize. That shows us that it is not so bad to have multiple-choice exams. That shows us that grading is subjective. (Observation #5, February 1,2005)

Jack also missed several opportunities to incorporate history of science in his instruction. In one occasion he gave a counter example of NOS language; he suggested that there was only one kind of scientific method in science and wrote on a slide the so-called steps of the scientific method. This kind of instruction is not recommended by science educators, such as McComas (1998) who says “this is one myth that may eventually be displaced … in favor of discussion of *methods* of science” (p. 58).

In one lecture, when Jack saw me in class, he came to tell me that he would talk about science and religion in this lecture. He devoted nearly ten minutes of his instructional time to science and religion. Here is the excerpt from that observation:

At 13:33 Jack stopped the lecture and took time to talk about what he saw on the web last night about the guy who invented the laser and maser. A male student left the class with his belongings. The teacher said that the guy who invented the laser won the Templeton award which is $1.6 million dollars and which is given to people who reconcile science and religion.

Jack: Do people think that there is some connection between science and religion? Raise your hands if you think so.

Five students raised their hands. Then Jack asked students to raise their hands if they thought that there was no connection between religion and science. Three students raised their hands. Jack then asked students to raise their hands if they thought that it doesn’t matter if there is connection or not. Around ten students raised their hands.

> *The teacher then started talking about the religion and science connection and said that these people with the Templeton awards were crazy to waste their money on something that does not contribute to society at all and asked students for their opinion. White female said that she is a religious person, but also a science major and that she combines them with no problem at all.* (Observation #15, March 10, 2005)

This talk was a good example of NOS language and addressed a controversial issue that always comes up in science classrooms and it is better to address it right on and to avoid any further confusion on the topic as recommended in NOS literature (Lederman, 1992). On a few occasions during the semester he pointed out the benefits of chemistry to the society. A few times Jack incorporated relevant examples from recent and everyday events to explain certain chemical concepts. Here is an excerpt that gives an example of that:

> *He tried to make students interested in studying science. He gave the example of the space ship that landed on the moon of Saturn, which is called Titan.*
>
> Jack: We placed a ship on the moon of Saturn. If that does not amaze you I don't know what will.
>
> *He tried to make the point that science is interesting to study.* (Observation #1, January 18, 2005)

Student actions

Students in this class were usually not on time for the lecture, a few students came 10 to 15 minutes late and sometimes a few students arrived one-half or one hour late. Furthermore, students left the class whenever they felt like it, usually for the restrooms or to get food from the vending machines outside the auditorium. They would leave for five minutes and come back again, and sometimes they would leave with their belongings early without waiting to the end of the lecture. Overall, students in Jack's class seemed disinterested with the lectures and showed signs of boredom with the lecture. On a few occasions, I saw signs that students did not understand the teacher's explanation, as they were talking among themselves and asking the students next to them what the instructor was saying. Students who were interested in the lecture usually preferred to sit in the front rows and were attentively listening with some taking notes and generally they were the same students. Students who were not interested usually sat in the back rows. Students who were preparing to leave the class become noisy when the time was up, even though the teacher was still talking and was not yet done with the lecture.

Summary

From the above detailed description of Jack's lectures we can see that Jack has a traditional teacher-centered instruction style, in which he mainly concentrated on problem solving with very little incorporation of history and philosophy of science and very little or no instruction geared towards the various aspects of NOS as recommended by researchers such as Akindehin (1988), Billeh and Hasan (1975), Carey and Strauss (1968, 1970), Jones (1969), Lavach (1969), and Ogunniyi (1983). It appears that the critical role and possible influences of other contextual variables of teaching science, such as the pressure to cover content and solve more problems, large class size, lack of management and organizational skills, Jack's concerns for students' abilities and motivation, and instructional constraints were more important for Jack than teaching for understanding of NOS.

Jack's Rationale for His Teaching

Jack gave explanations for his teaching and provided rationale for using or not using certain teaching techniques in his follow-up interview. His views are presented and grouped according to emerging themes.

Class size effect

Jack emphasized that he encountered various problems when teaching in a large introductory class. Jack said the class size effect "is enormous, it makes all the difference," because it is hard to interact with students in a class of 100 something. "It is hard to get students to talk; it is hard to get students to be fully engaged, to have any single back-and-forth." He pointed out the peer pressure not to participate in the lecture in such a large class as follows:

> Even if they are concerned about how the professor thinks, they are also concerned very much about how their peers think. Not that they are necessarily either right or wrong about what they are saying, but they might be; there are other things that come up. Is this guy a suck up because he is talking to the professor, is he just brown nosing trying to win points, or is he an idiot, or is he really smart, but still is sucking up? Nobody wants to look like an idiot, not because they care what the professor thinks, but because of what that pretty girl over there thinks or that good looking guy over there thinks, or they don't want to look like they are talking to the professor, because they will think that guy over there will think that she is too smart and not attractive. I mean all those weird, strange things come into play.

Jack personally believed "classes work best when students have a question or even an idea that can be blurted out at the time, but it is harder to get that to happen in a big class." He thought, "Whenever you can have a smaller class it is a better class and it works really well, because it is easier to maintain collective focus of what you are trying to talk about." Jack explained that the reason why they have large classes in their university is that they do not have enough professors who can teach those introductory classes. When asked what problems he encountered while teaching introductory science classes, Jack saw the lack of motivation of students and their fear of science, as the main obstacles. Jack's problems were "getting students to be part of the process, getting students to interact, getting students to do the problem sets" and "the bigger the class the harder it is," because "when the classes are big it makes it very hard to relate in so many ways." When asked how we should overcome these problems Jack said, "Making smaller classes," making "interesting problems," making "interesting lectures," and "try to find a way to motivate the students."

Instructional strategies and problems

Jack used the overhead projector a lot when presenting his lecture. Jack said that using the overhead projector slows him down and gives students a better chance to take notes. And also "in a very odd sort of way," because his "hand writing is very horrible, students have to struggle to be able to read it, but that means they are reading it, they actually have to figure out" what he wrote.

Jack pointed out that the large class size and pressure to cover content prevents him from utilizing group work in his instruction. He has "an open mind to different modes of instruction, but wouldn't know how to do that with a class that size." At one point in his instruction, he used complex sophisticated science language, such as some science units and formulas that can sometimes be hard for students to understand. When asked why, Jack said "the units are extremely important" and there is an art to them. He also said units and equations are "the language of chemistry." Jack saw using units and formulas as extremely important.

Jack incorporated, to some degree, Q&A type teaching in his instruction and gave varying reasons why he does it. Jack said he used Q&A just to keep the lecture "more interesting" for students and "it is a question of getting information from the students" with the hope of modifying the "interface with the students better," but acknowledged that "it is just hard to get students to do it." He pointed out that it is a matter of communication skills and that it "is an interpersonal dynamic, a complex thing, some people are very good at it, and some people get better at it as they get older and are more confident and some people are never good at it and that is the way it is." Jack emphasized that "people do not get jobs as professors, because they are going to be great teachers," but because they are going to be good researchers with good communication skills who care, which is worrisome for science education in general, especially in the introductory classes, where students need the most capable teachers with a good pedagogical background to help them in the understanding and workings of science according to their developmental level. Clearly Q&A was seen by Jack as a good instructional strategy used to engage students with the lecture and help him to see his students' level of understanding of the lecture.

Jack incorporated some history of science. He talked about the important scientists who came up when teaching. Jack includes history to put "the scientific information, a scientific knowledge in a human context" and to make "something relevant." He uses history of science "every chance" he gets. Jack saw the use of history of science as an important instructional strategy that can help him to put "the scientific information in a human context" and to make science relevant to students. He incorporates history of science when he sees it is relevant and important in a lecture. This shows that if intended instructors can incorporate history of science as recommended by various science philosophers and educators.

Jack used problem solving as his main instructional tool. He solved problems after every new concept he introduced in his lectures. Jack explained that the reason he uses problem solving is because "in chemistry that is the way it is done, chemistry is all about solving problems, you live and die by problems, problems are what actually illustrates the concepts, illustrates the mechanics of how you do it." The fact that Jack saw problem solving as the main feature of chemistry is in contrast to science education literature, because such a priority in teaching science to freshmen students gives a false image of science and makes students think that science is all about mathematics. Also, such a way of teaching science leaves very little room for incorporating demonstrations, relevant examples, and some NOS aspects in instruction, which Jack said he wanted to incorporate.

In all of the classes that I observed, some students were not involved with the lecture at all. Some were leaving for the restrooms, some were coming late to class or leaving the class early, some were reading the school newspaper or solving puzzles, and some were sleeping. Jack said as long as students do those activities quietly and “they don’t interrupt the students and their friends” and do not disrupt the class he does not care. He said, “if it is a small class that is a different matter, because then you can’t be disruptive, but in a big class, fine.” Clearly students’ distractions with the lecture weren’t a big problem for Jack. This may be due to the large class size, as pointed out by Jack, because in a large class it was important for the instructors just to keep the students quiet and not to care whether they listen and participate or not.

Suggestions and qualifications to teach introductory classes

Jack enjoys teaching, because it keeps him fresh and makes him think that he is “doing something positive.” Clearly teaching for Jack was not a burden and something that he has to do in order to keep doing his research. He enjoyed it and wanted to give something back to his students. I asked Jack, what do you think the qualifications should be to teach an introductory science class in college? Jack answered “qualifications start with technical confidence, the person must feel completely confident with all the scientific material that needs to be taught.” He also said that the person must have some experience, at least four or five years as teaching assistants with more than one professor, and suggested “maybe a person who did have training in education would be better,” because he thought:

> People who have an education background are more aware of things that pertain to younger students, development rates, what develops first, what develops later, the learning process. They are more aware of that than non-education trained people. I don’t know how important that is when people are mature, as mature as anyone between 18 and 22, sometimes that is not very mature.

When asked for suggestions to improve introductory science classes, Jack gave several recommendations. Jack suggested changing the curricula, but pointed out that “it presents an enormous number of logistical and administrative difficulties.” He also suggested incorporating demonstrations into instruction to get students interested. Reducing the large class size was seen as the main way to improve these courses by Jack. He also suggested more hands-on activities in those courses.

Discussion and Conclusion

The findings suggest that Jack preferred to use the traditional teacher-centered lecturing as his teaching style. His main concern was to cover more content, develop the problem-solving skills of his students, and to teach the fundamental principles of chemistry to the students without paying special importance to the aspects of NOS. This is in contrast to the findings and suggestions of others (Akindehin, 1988; Billeh & Hasan, 1975; Carey & Strauss, 1968, 1970; Jones, 1969; Lavach, 1969; Lederman, 1999; Ogunniyi, 1983), who call for an explicit approach to the teaching of NOS, in which learners are provided with opportunities to reflect on their experiences from within a conceptual framework that explains some aspects of NOS. This reveals that having complex and mixed understanding of the NOS aspects and lack of knowledge of how and when to use these NOS aspects affects the purposeful teaching and incorporation of NOS in instruction (Shulman, 1986). This also shows that the critical role and possible influences of other variables of teaching science, such as drive to cover more content, large class size, lack of management and organizational skills, and instructors' concerns for students' abilities and motivation are more important for Jack than teaching for NOS understanding as affirmed by others (Abd-El-Khalick, Bell, & Lederman, 1998; Brickhouse & Bodner, 1992; Duschl & Wright, 1989; Hodson, 1993; Lantz & Kass, 1987; Lederman, 1999; Lederman & Latz, 1995).

On the other hand, the follow-up interviews with Jack reveal that he stated at least one of the NOS aspects as his desired goal for students. He stated that he talks about the history of science in his instruction when he sees it is relevant to a particular topic. However, I observed Jack did not purposefully incorporate the history and philosophy of science in his instruction, and did not have instruction geared toward the various aspects of NOS. Research literature clearly indicates that students, teachers, lay people, and even scientists do not necessarily hold adequate conceptions about many of the NOS aspects (Irez, 2006; Karakas, 2008; Lederman, 1992; McComas, 1998; Schwartz, 2004). Similarly, this study supports this claim and reveals that the participant in this research also held some inadequate conceptions about NOS.

There are some limitations of this research. Relevant topics of NOS in K-16 science education guided the development of the interview questions used in collecting data for this study. What the participant discussed was ultimately guided by these perspectives. There may be additional features of epistemological views held by other scientists that were not elicited in this study. Nevertheless, the perspectives pursued and gained through the present study were those deemed most relevant for teaching NOS in K-16 science education.

The study also highlights the need for training science faculty on effective teaching methods. Jack's teacher training does not strike the reader as someone who has been taught how to teach NOS. Jack was trained to do research in a laboratory setting, but teaching requires a different set of skills. Science faculty, especially ones who teach introductory science courses, should receive training on effective teaching methods to freshmen students for more meaningful instruction to occur in future science classrooms. They could also receive training on effective NOS teaching methods, they should know that simply doing research does not guarantee good NOS teaching to freshman students. Workshops on the aspects of NOS and its effective teaching could be held and lab scientists should be made aware of the ever expanding science education literature.

This study attempted to add one more example of college science teaching experience to the literature and call for reform in higher science education. This can be achieved by restructuring the system and making small discussion type introductory science classes, which are taught by science faculty who have some experience in pedagogy and in how students learn. This, in turn, will have implications regarding the personnel hired to teach these courses. However, the culture of science departments may be such that they do not really care about hiring good teachers most of them want good researchers.

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Appendix A

In my first interview I asked Jack the following questions:

- Where are you from?
- Where did you finish your elementary, middle, and high school education?
- What type of school did you go to (public, private, home schooling etc.)?
- Where did you go for undergraduate education?
- Where did you go for master's education?
- Where did you go for PhD education?
- Do you have a post doctorate?
- How long have you been teaching this course?
- Did you teach science classes anywhere else, different from this institution?
- Looking back at your high school or college years how would you describe the best science teacher or teachers you had? Why was he/she so good?
- Can you describe her/his or their best qualities?
- What interested you in science?
- How do you define science?
- Why did you choose this particular field of science?
- How did your family affect you in pursuing science?
- How did your educational experience prepare you to understand science?
- What kind of science books do you read for enjoyment?
- What scientific controversies have you followed?
- How do you know something is science or scientific?
- How do you see scientists do science?
- How would you describe the role of creativity in science?
- How would you compare science and religion?
- How would you compare science and art? How are they similar and different?
- How would you compare theory and law in science?
- How are inferences and observations in science different and how are they similar?
- What goals do you have for your students? What do you want your students to know about - science? Research process? Generation and verification of knowledge?
- How do you see your students' understanding of science before they came here?

- What kind of strategies do you use to teach about nature of science?
- How do you or do you incorporate the history of science in your instruction?
- How do you or do you incorporate other cultures' contributions to science?
- How do you or do you use nature of science examples as explanations in your introductory science course?
- How do you assess your students' understandings of NOS?
- How do you think we can make students more aware of how science works?
- How do you think we can make students more scientifically literate?
- What role do you see yourself playing in teacher preparation with regard to future teachers' understanding of NOS?

I also asked him probing questions during the interviews when I saw it as necessary. Examples of probing questions were: Can you elaborate more on the issue? How exactly is that? What do you mean by that? Can you explain?

Appendix B

Follow-up Questions for Jack:

- How do you or do you incorporate other cultural contribution to science in instruction?
- Do you see any connection between what students might learn in this course and their role as citizens? For example, do you think what they learn about scientific inquiry in this course might be relevant for their judgments about whether creationism should be taught in schools?
- How does the class size affect your instruction?
- I observed that you use a lot of problem solving in your instruction. Why did you do that? Do you think students understand a concept better if they solve a lot of problems about it?
- I observed you did not incorporate any group work in your instruction. Why is that?
- I noticed that some students leave the class early, some go to restrooms, and some came to class late. What do you think was going on?
- I observed that you used the overhead projector a lot. Why did you do that? What was the reason for that? Did you have access to any other type of an instructional tool?
- I observed that sometimes you used complex vocabulary, such as using chemical units, and a lot of math and chemical formulas while explaining a concept. What were you thinking about when you did that?
- I observed that there was a lot of eating going on in this class, the class period was scheduled for lunch time. How did this affect your instruction?
- I observed that you were making eye contacts with students sitting in front rows generally. Why did you do that? What was the reason for that?
- I observed that you tried to incorporate question-answer type instruction in your lectures. What were you thinking about when you did that? How many students do you want to be involved in your lecture? How do you know when they are involved (cell phones, puzzle solving)? Do you notice when they use their cell phones or do puzzles in class? Is this a concern for you?
- I observed that in very few occasions you used history of science in your instruction, such as giving background information about the development of a

concept or a life of a scientist. How do you think that enriches your instruction? When does teaching history in a science class have importance? When do you use it?

- I observed that very few times you emphasized the importance of the units, numbers and mathematics in science and you said, “practice makes it prefect,” meaning solving a lot of problems will make students good in the numbers.
- Why did you do that? What was the reason for that? What were you thinking when you did that?
- I observed that a few times you incorporated relevant examples from recent and everyday events to explain a certain chemical concept. What was the reason for that?
- Please tell me something about yourself?
- What are your interests?
- How central is science to your daily life?
- What do you enjoy about teaching?
- What do you enjoy about science?
- Have you taken any history or philosophy of science courses?
- Are you working on any research project at the present?
- What do you think qualifications should be for teaching introductory science classes?

Author Note

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Article Citation

Karakas, M. (2010). A case of one professor’s teaching and use of nature of science in an introductory chemistry course. *The Qualitative Report*, *15*(1), 94-121. Retrieved from http://www.nova.edu/ssss/QR/QR15-1/karakas.pdf