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HOW TO TEACH INTRODUCTORY SCIENCE CLASESS: VIEWS OF FEW SCIENTISTS

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Abstract:
This paper helps instructors reflect on their experiences with teaching introductory science classes. Participants were 17 science professors from five different universities in the northeastern US. Data were collected using qualitative techniques and especially semi-structured interviews. Findings point out the importance of active teaching methods and call for teaching science in labs, use of group work and case studies in teaching science to freshmen students, and giving students critical thinking skills.

Keywords: reflective practice, introductory science teaching, science education, higher education, effective teaching, qualitative study

1. Introduction

The long history of the advocacy for teaching about science, nature of science (NOS) and increased scientific literacy 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 American schools as early as 1920. Currently, the National Research Council (NRC) has stated 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)

Most recently NOS has been included as a critical component of scientific literacy (AAAS, 1989; NSTA, 1982; NRC, 1996). 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

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informed consumers of science so 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. As indicated earlier, the National Science Educational Standards (NRC, 1996) explicitly state that helping students develop adequate understanding of NOS should be one of the primary objectives for all science teachers. However, in order for science teachers to teach about NOS, they need instruction that explicitly addresses the workings of science not only in their pre-service science methods courses, but also in their undergraduate introductory science courses. Having instructors who understand the workings of science in their early introductory level science courses becomes important. Furthermore, figuring out how these science instructors teach about science and NOS and highlighting their recommendations for teaching about science might be important too. Clearly, science educators (Abd-El-Khalick, & Lederman, 2000; Duschl, 1985; Lederman, 1992, Irez, 2006; Karakas, 2006, 2008, 2011; Schwartz, 2004) and scientists have been persistent in their advocacy for improved student understanding of NOS over the past several decades. Kimball (1967-68) indicated that this objective is one of the most commonly stated objectives in science education. Saunders (1955) went further and described it as the most important purpose of science teaching. The development of an "*adequate understanding of the nature of science*" or an understanding of *"science as a way of knowing"* continues to be convincingly advocated as desired outcome of science instruction (Lederman, 1992, p.331).

Moreover, numbers of teacher educators have indicated that teacher education programs are not graduating teachers adequately prepared to educate future generations (Lee, 2005). Thus, reflective teacher education has been investigated as an alternative approach in teacher preparation (Dewey, 1933; Lee, 2005; Schon, 1987). Dewey's model of reflective practice marked the beginning of reflective teacher education (Richardson, 1990; Valli, 1992). The main goal of reflective teacher education is *"to develop teachers' reasoning about why they employ certain instructional strategies and how they can improve their teaching to have a positive effect on students"* (Lee, 2005, p.699). However, due to the lack of a clear definition of reflection and vague criteria to assess the quality of reflective thinking, there have been problems in implementing reflective activities in teacher education programs (Lee, 2005; Rodgers, 2002). This paper is an effort to help science professors' reflect on their teaching and to better understand their recommendations on how to teach introductory science classes.

In the 1980s, Schon (1987) made the term "reflective thinking" an important theme in teacher education. However, the enthusiasm for reflective teacher education has not translated into a consensus across the teacher education community of what a reflective teacher education program should be (Kember, Jones, Loke, McKay, Sinclair, Tse, Webb, Wong, Wong, Yeung, 2000; Rodgers, 2002). Even though researchers adopt various definitions and theoretical frameworks for reflective thinking, there are general themes of defining and assessing the quality of reflective thinking. Dewey (1933) defined the reflective thinking process as an experience, spontaneous interpretation of the experience, naming the problems or the questions that arises out of the experience, and generating possible explanations for the problems or questions posed (as cited in Lee, 2005). The meaning of reflection (or reflective thinking) in educational research has changed over time: from *"careful consideration, a thought or an opinion resulting from such consideration"* (The American Heritage College Dictionary as cited in Lee, 2005) to any form of thinking. In other words, the levels of reflection include not only reflective thinking as defined by Dewey, but also non-reflective action (Mezirow, 1991; Valli, 1990), habitual action (Kember et al., 1999), and so forth (as cited in Lee, 2005). It is necessary to emphasize the recursive character of these stages (each one strongly depends on all stages before it) and the cyclical nature of the reflective thinking process (Lee, 2005; Dewey, 1933; Eby & Kujawa, 1994; Pugach & Johnson, 1990; Schon, 1987). Through the reflective process, educators aim to develop effective teaching habits (Dewey, 1933; Schon, 1987; Sparks-Langer & Colton, 1991; Taggart, 1996). And this study aims to show the science instructors instances of reflective thinking.

Additionally, the search for effective teachers has been going on for more than hundred years (Aagaard & Skidmore, 2002). Most of the literature on effective teachers argues that both personal characteristics and teaching methods seem to be important (Cotton, 1995; Gresh, 1995; Norton, 1997; Demmon-Berger, 1986; Witcher, Onwuegbuzie, Minor, 2001; Aagaard & Skidmore, 2002; Czerniak & Shriver, 1994; Davis & Smithey, 2009; Fitzgerald, Dawson, & Hackling, 2013; Karakas, 2013). In some studies, one of the characteristics of teachers was their favorable interaction with their students (Tobin & Fraser, 1990; Treagust, 1991). In other studies, these favorable interactions were identified as helping, friendly, caring, patient, enthusiastic, flexible, engaging, and understanding (teacher trusts us, helps us with our work) (Fisher, Fraser, and Wubbles, 1993; Fisher & Rickards, 1997, Wubbels & Levy, 1993; Rawnsley & Fisher, 1997; Atwater, 2000; Waldrip & Fisher, 2003; Cone, 2012; Olson, Bruxvoort, & Haar, 2016). Cone (2012) says that *'caring teachers are not necessarily seen as permissive, allowing students to have their ways. Conversely, they set limits, provide structure, have high expectations, and push students to succeed, they trust and respect students and recognize them as individuals, while building on their strengths … they are confident in their own teaching practices and believe that all students can learn and thus are persistent and resilient, even in the face of obstacles'* (p. 892). Also, Tobin and Fraser (1990) point out that effective teachers use efficient management skills, track students' understanding throughout lessons, encourage students to be engaged in their learning, and strive to maintain a positive classroom environment. Recent studies have begun to point out the importance of active learning and carefully analyzing what teachers pay attention to, especially in reference to student thinking (Coffey, Hammer, Levin, & Grant, 2011; Hammer & van Zee, 2006; Roth, Garnier, Chen, Lemmens, Schwille, & Wickler, 2011; Russ, Coffey, Hammer, & Hutchison, 2009). These studies highlight the importance of analyzing what teachers attend to in order to create learning opportunities that better support teachers' ability to genuinely engage with students' ideas in the classroom (Talanquer, Tomanek, & Novodvorsky, 2012).

In summary, the research on NOS, reflective and effective teaching outlined the theoretical framework of this study. This study will try to explore the views of science professors on their teaching and how they try to teach introductory science classes. The research question is:

- What science instructors say on how to teach introductory science classes?

2. Methodology

The study involved seventeen participants. The participants were from five different institutions, one Ivy League university (3 males), one private research university (4 males and 1 female), one state college (3 males), one private college (2 females and 1 male) and one community college (2 males and 1 female) in the northeastern United States. I sent e-mails to total of 30 science faculty members who taught introductory chemistry, physics, biology, and earth science courses at these institutions asking for their permission to be interviewed. Of those participants, 17 responded positively and were included in the study. The most commonly stated reason for not participating in the study was time constraints. These participants were part of a larger study (Karakas, 2006, 2008) and some different aspects of the findings were reported in another study (Karakas, 2018). All participants gave their consent to participate in the study. I arranged the interview times according to participants' schedules via emails and via visiting some of the participants in their offices. I conducted one in-depth individual interview with each of the participants during the fall semester of 2004 and spring semester of 2005. The interview times ranged between 25 minutes and one hour and 30 minutes; the average interview time was approximately 50 minutes. I gave pseudonyms to all participants in the study to keep their identity anonymous. I conducted all the interviews in person in each scientist's office, except one, Don, who came to my office. All but two of the interviews were conducted in a single session. Jack and Pat's interviews were conducted in two sessions, because of time constraints. Table 1 summarizes the sample, grouped by discipline areas.

Table 1: Summary of scientists grouped by disciplines

Discipline	Number of participants	Average years of teaching experience	Number of male participants	Number of female participants
Biology	4	5.25	3	1
Earth science	3	13	2	1
Chemistry	4	19	2	2
Physics	6	21	6	0
Total	**17**	**15.2**	**13**	**4**

I employed qualitative methods, and particularly the interview aspect of ethnographic research design, in collecting data. Ethnographic designs, as Creswell (2002) describes them, *"are qualitative research procedures for describing, analyzing, and interpreting a culture-sharing group's shared patterns of behavior, beliefs, and language that develop over time"* (p. 481). The study focused on how science professors' views emerge. The in-depth/open-ended nature of interviews, as Bogdan and Biklen (2006) write, *"allows the subjects to answer from their own frame of reference rather than from one structured by prearranged* *questions"* (p. 3). Also, I used loosely structured interview guides (see Appendix A), as recommended by Bogdan and Biklen (2006), in order to *"get the subjects to freely express their thoughts around particular topics"* (p. 3). In this study, the topic was how to teach introductory science classes. The researcher developed loosely structured interview questions used in this study. I recorded the interviews on a digital voice recorder and later transferred them to a personal computer.

Present study used qualitative methods in analysis of data. The first step in the analysis was data organization procedures recommended by Bogdan and Biklen (2006). In organizing the data, I revisited each interview and listened to each audiotape while reviewing the transcripts to ensure the accuracy of data. Each participant's interview transcript was later analyzed according to data analysis procedures described by Bogdan and Biklen (2006), which call for development of coding categories, mechanical sorting of data, and analysis of data within each coding category. Initial codes were supplemented with emergent main categories and sub-codes (Bogdan & Biklen, 2006). For example, while reading a transcript, I coded certain views as teach in labs by doing science, teach the basics of science, class on history of science, class on history of medicine, class on religion versus science, use group work, let students ask questions, incorporate case studies in instruction, make science interesting and attractive to students, give students critical thinking skills, get students involved with current literature, give students wide breath of information, stir up students interest, improve K-12 science education, improve K-12 science teachers' skills, the aim of college education, setting up a good teaching example, improve intra-disciplinary communications, more scientists should go into teaching. In average there were identified more then 30 codes for each participant. Later on, these codes were collapsed into categories such as use of active teaching methods, class on history of science, curriculum concerns, and make science interesting and attractive. In this study, I used a realist mode to represent the participants' perspectives through closely edited quotations and interpretations of those quotations (Creswell, 2002; Van Maanen, 1988). Thus, in this study I let the participants share their thoughts. 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 individual beliefs, participants' *"talk reflects the communities and language games in which they participate, for there are no private languages"* (Roth & Lucas, 1997, p. 147). Thus, I make no claims that the data gathered represents informants' permanent and deep-seated views; rather I read them as socially constructed in the moment. While a qualitative researcher intends to tell a story from the view of the participants, he or she can never divorce the words of the participants 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 what meaning to make from participants' quotations, I try to put as many quotations from the participants 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 their own background, because they may be different from the researcher. I present the results as a description of emergent themes that developed through the analysis. I coded and collapsed the interviews into categories. I also grouped the emerging main themes into sub-themes to give more accurate representation of faculty's thoughts about how should we teach introductory science courses as each one of them bring their individual experiences in their specific contexts.

3. Findings

Scientists, throughout their interviews, gave various recommendations on how to teach science and NOS. Majority of the scientists suggested doing more hands on activities, more laboratory activities, and recommended incorporation of more history of science in instruction. Few suggested teaching the basics of science. One recommended designing a program that has a separate class on the nature and history of science. Tow scientists proposed using group work as a teaching strategy. Another scientist called for making students feel comfortable asking questions. Some recommended giving students critical thinking skills. Others called for getting students involved more with current literature. Three more called for making science interesting and attractive to students. One recommended designing a course on the history of medicine. Another proposed a course that specifically discusses creationism versus evolution controversy. Yet two scientists called for incorporation of case studies in instruction. Below results are presented in main themes and sub-themes. The results were grouped in four major themes and each one of the themes was organized in various sub-themes according to findings.

3.1. Use of active teaching methods

Most of the participants suggested use of active teaching methods to improve introductory science classes.

3.1.1. Teach science in labs by "doing science"

Majority of the scientists called for teaching science in laboratories to give students a chance for more hands on activities and solving real research questions, and where they can learn science by "doing science". Furthermore, they recommended incorporation of more history of science in instruction. Below are excerpts that highlight those views:

> *"... I think the laboratory is a very valuable way of getting across the way science works, by having students actually go through the process of discovery themselves, and to the extend possible which is you know may be one or two percent ah involving students in research, which is actually how I got interested in doing science myself."* (Donna)

> *"... Again because it is a non-lab class that makes it harder, the best place to learn how science works is in a lab. Ah, so you know I have incorporated some activities into the lecture part of the class, where they can set up certain things and make observations and draw conclusions, but it is not the same as having real focus lab activities. What I try to*

do the last two years I taught the class was taking out them to actually discuss the scientific method and to have them design and carry out an experiment of their choice. Ah, something related to microbiology whatever they wanted and if it was reasonable. I will get them the supplies and they will do it in out of class activity and then write a paper to describe what they have done. And I don't know how effective that was. I mean they certainly were entertained by being able to do something as to what is they left the class knowing more about how science is done then was they came in, ah I can't say for certain. But we did discuss the scientific method, the hardest thing to get across to students in that level especially without a lab is the idea that there is quantitative analysis of data. And I did some exercises to try to show them that there is a variance in populations and sample of populations and that there is variance of data and something like that, ah but it is very hard and it really takes away from the amount of time that is spend on the content area, the subject matter. So, I think that the tendency in general classes, classes especially if there is not a lab, are really so much about how that knowledge is derived…..

I – How do you think we can make students more aware of how science works?

P – I think that the more inquiry-based instruction is done in laboratory environment the better in terms of making them aware of how science works. I think that there are some great stories that can be told about how our understanding of certain processes changes over time. Processes rather scientific that I think that an important part of understanding science is an understanding how cool it is, ah one principle that in microbiology is constantly changing taxonomy where organisms are moved in and out of different genesis all the time for all sorts of reasons as the criteria of classification changes. And that you know give them time to investigate that would definitely help to improve students' understandings." (Liam)

*"I mean part of it is these things we do in the classroom, part of it is what they do in the laboratory. They actually make measurements, they verify conservation laws and don't verify them, they look at the uncertainties in the measurement. And so, I think the laboratory is one way of them seeing how science works. Another way, which may be we just think about it, is may be we should take an individual who developed something Faraday for example who partly by chance discovered the law of electromagnetic conduction. May be we need to follow person like Carson who did more for the history of science and then to understand the physics and the history as well. So, we have to look at the individual and see what they did and that might be very appropriate. So seeing and just trying some things in the laboratory, you got to have a science, chemistry, physics or lab based sciences, you got to do that. And then may be following something through from beginning to end. So, you learn one thing there, but you followed it through the way. I haven't tried that part." (*Ron)

"I think by introducing them to researchers that is, many of them belong to true professional how one could do that or introduce them that profession. But, they are also going to be chemist I think that by actually putting them in real research situations.

Otherwise, one can try to simulate that by reading with them some case studies and some specific things." (Rich)

"I think it is a big thing and I guess this is a very well recognized. I think big part of it is having students actually be involved in the practice of science, getting students involved in research, give them a job, give them an experiment that they can do research, just show them simply the process of seeing how mistakes are been made and then solved. That sort of stuff, I think you know letting them to see it for themselves." (Tom)

"Getting students more aware of how science works! Ah (long pause) I thought a lot about this and acted on to the best of my ability, you know things like this, you know I try to show them by example that is just certainly the way I learned science. It is not you know being told how it is done; it is being shown how it is done. One thing that I do that I ever since done I try to make feel them the very best classes I have taken demonstrations how science sometimes gets hopes fouled up..." (Josh)

"By helping them to understand that they are already doing it and that it is not scary, because they do it all the time, and then when they see what it is that they are doing, the process that they do they will know that that is the process for science." (Tina)

"… A laboratory base course would be improvement in some ways and I think may be not an improvement in other ways, ah more time, beginning earlier would be my solution of the problem. If one had a better educated set of instructors at the elementary level and at the middle school, high school level, if these kind of questions were addressed right there. How come people are so successful on the Earth going around the sun rather then vise versa is by the fact that it is totally contra intuitive that the Earth moves around the sun why is that so successful, because it started early. And to try to come in late ah it is tough…
I – Ok, how do you or do you assess your students understanding of science?
P – The way which I think is possibly hopeful is the one which I just described. The ideal case is to prepare them via a presentation of some theoretical principles if you like and then do something which they can see, which involves those principles and then make them figure out how those principles, you know analyze the situation, and make them figure out how the principles, make them do it. And as they muddle around and get confused, they can ask questions, I can intervene, and it is basically a mentoring model. And it is also a model, if you like, based upon research, I mean if you have a research project, you go into laboratory, you do something and you get some results and then you have to go figure out, you know what the implications are, why my theory works, why my theory didn't work, you know what compound effect is it worth, and things like that. So it is a metric style of instruction or it is a research based, if you like, approach to learning, either way. But that I think is the only thing, which I consider really useful. I mean, being clear in your presentation of the ideas and the concepts is a good starting point. But I don't see the students really internalizing and making it their own until they

grapple with it, and sometimes grab one who failed and come back and grapple with it again..." (Don)

The recommendation of teaching science implicitly by "doing science" is in contrast to suggestions of others (Akindehin, 1988; Billeh & Hasan, 1975; Carey & Strauss, 1968, 1970; Jones, 1969; Lavach, 1969; Ongunniyi, 1983) who call for "explicit" teaching of science and NOS, where learners are provided with opportunities to reflect on their experiences. These views of the participants reveal that they are not quite familiar with the new studies in science education. However, their suggestion to incorporate history of science in instruction is in agreement with the scientists advocating the "explicit" teaching of NOS.

3.1.2. Teach the basics of science

Pat and Frank, who were teaching in a community college, recommended teaching the basics of science to make students more aware of how science works:

"… in freshman chemistry level the best we can do is give them the background on the scientific process, but again it doesn't deal with the state of the art. You know, it doesn't deal with the cutting edge research that people are doing. So, I don't know if that really helps you, but that is my answer." (Pat)

"I – How do you think we can make students more aware of how science works?
P – Well, (pause) I think just basic science. I whish everybody was required to take a physics course and could pass it, because that is where you learn how science works more then any other course. I think, in introductory physics course we just have to use, I am an old fashioned guy, a ruler, a stop watch, a triple beam balance that is how science works. And so I would love to see everybody have to take a course that was like a physics course. We have one here a physical science course that is just measurement oriented, simple graphics, some interpretations, it is pretty tough though. Ah but besides that in my own introductory astronomy course I think they have to be lead, you have to lead them through the process a couple of times. Ah I think you have to show them how science is done. I try to tell them that in this class one of the analogies I use is that we a kind of in a summer camp and they are the campers and I am the counselor and everyday you learn to get up and go to a little trip to the woods and I will be pointing out some of the things along the way. And they have to come to class so they, because you don't know, if they are not in your class you don't know if they miss all the things that you want them to know. So, I kind of think of it as scientists we have to be a guide to the non-scientists and show them how it is done for a while. And then kind of work them into it, so that they can do a little bit for themselves, give them some numerical analysis, ask them to make some observations and then come to some conclusion." (Frank)

Ron and Don suggested teaching the basics of science first and later on incorporating history of science and controversial issues, such as science vs. religion:

"Oh and that hold through for our science majors as well as for my elementary education majors. I think that they have to understand…, and again this probably is more theory then practice for myself, but I think sometimes following something that is, that is controversial, may be following a history of science and religion that is certainly one, you can use that as an illustration, you can understand may be what is some of another theory expenditures are, may be there is something very just science and politics involved so that they become literate by being able to explain to their congress person why this action would be fault or their school board president or something like that. So that type of things is probably good and also I think that they just have to be literate by understanding the fundamentals of our fields and if I don't teach them that then the approach isn't worth being, unless they understand the fundamentals." (Ron)

"Well, as you see already at the moment my goal has been simply to raise their factual knowledge base by some increment and the more successful that is the better I feel. And I regard that as a kind of a prerequisite to going beyond those deeper issues. It seems to me that deeper issues don't really stand on their own. I mean you can talk about scientific methodology all you want, but it is kind of water off the ducks and back unless you have something in front of you that you can really see, feel, and do it, with these issues of public policy and possible tensions between religion and science, I think can involve one. But one can't do that well until one sort of has the lay of the land so to speak and kind of has the bases of information on which to build further deeper issues. So the progression I see is, you know first of all you construct by whatever means you can and in knowledgeable lay land and on that basis then you try to begin to make them aware of policy, procedures of science, and deeper issues and that is the ideal to which one tries to reach." (Don)

3.1.3. Use group work as a teaching strategy

Peter and Rich proposed using group work as a teaching strategy to help students better understand how science works:

"I – How do you think we can make students more aware of how science works?
P – Ah, again it has got to be in a format that is not just lecturing. It is something that really allows them the ability to have smaller groups of people whether it is having your paper presented in smaller groups and to discuss scientific issues and to debate things. That would be one way of doing it, given that I am not going to be able to have just groups of 30 students or even to be much more active. It really requires that you have more ability to have students interact with each other allow them to just sit down and have them teaching each other and you watching over and have, there is some fundamental change in how the classroom style is done." (Peter)

"Ah, I think that somehow if one can get students involved themselves as not as passive receivers of teaching, but as somehow teachers perhaps of other students, ah to this what I said about making up or as tutors to other students. I think this is actually the most

productive way of having students to be teachers and not to put, it is very difficult, they don't receive as that. That is the only thing." (Rich)

3.1.4. Incorporate case studies in instruction

Max and Rich suggested incorporating case studies in instruction to help students be aware of how science works:

"Ah (long pause) you know by discussing good case studies, I think. For example, this semester I do different models for the structure of the Milky Way galaxy and different ideas of what, whether there are galaxies other then the Milky Way galaxy, really is a major controversies if you want at the time they took 20, 30, 40, 50 years, to gave them case studies like that." (Max)

"… Otherwise, one can try to simulate that by reading with them some case studies and some specific things." (Rich)

3.1.5. Give students critical thinking skills

Pat and Frank suggested that giving students critical thinking skills would help them question the information on the media and whether somebody is manipulating scientific facts to support their position:

"I – So, how do you think we can make them more scientifically literate people?
P – (Long pause) if you can make them think critically about what they read that helps. What I mean is if you pick up a newspaper article about some facts and figures, but you look at to the statistics on it and they are saying well 25% plus or minus 10% well that is almost meaningless. If you can help them to see through things like that I think that helps them to understand what is going on, because a lot of what you see as scientifically in the newspapers you know just regular newspapers it is facts and figures and the figures may or may not have merit. So, just helping them, I mean scientifically literate is such a broad thing you know, but just helping them read things critically will help. And at the end doing that little gut check that tells you does this makes sense or does it not that is really what I strive for. You know, I always tell them do a little gut check, does this feel right, does this make sense. And that is, if they go out in the world asking that question I did some long way towards scientific literacy, does that make sense, ok." (Pat)

"I - How do you think we can make them more scientifically literate people?
P – Make them as more scientifically literate, you got to, well let's see, make them more scientifically literate. They should read more about what is going on in the current news. I don't think they need to read the journals, but there is a lot of science in a newspaper. They should be skeptical; they should question authority that is part of being scientific. So I think that to make students more scientifically literate they need, you need to have them read more, question more and answer the question you know what I, try to answer you know why is this thing solved. I guess that would be, I mean they should have some

the kind of believe in mathematics too, because you can lie with numbers and you got to recognize if somebody is manipulating the numbers to support their position, which I think happens all the time. You know even scientists manipulate the numbers to support their position, they are not supposed to, the numbers are not supposed to dictate, but it doesn't work really. So you know people have to be skeptical and they have to be able to see through, see the difference between what is science and what is not." (Frank)

Jack suggested that if we can get students feel comfortable asking questions, we can "find out what they don't know" and that can help us improve out teaching:

"… I guess the all classes I teach I want them to, it hardly ever happens perfectly, but if you can get few students to feel comfortable asking questions, it is very good, because then you find out what they don't know. Otherwise, you just shooting in the dark, you have no idea whether you actually saying things that students can appreciate, but if you can get them to ask few questions, if you can get one brave person to ask questions, it is usually guarantied that there are five more in any class that are wondering about the same question, (laughingly) but they don't have the courage to ask, you know what I mean. And how you can get people feel comfortable that way and realize that it has no affect on their grade other then possibly making them smarter and helping them getting better grades, then I don't know how that is…."(Jack)

3.2. Class on history of science

3.2.1. Design a class on nature and history of science

Liam, who was also teaching in a community college, proposed designing an academic program that has a separate course on the nature and history of science:

"Hum (pause) you know I would hope that somebody who is going into education has a solid exposure to what science is. I am not sure where they will get that, if I were designing an academic program from scratch, I would almost say that there should be a separate class on the nature of science, and the history of science, and doing of science that teachers perhaps scientists, in fact I don't see curricula as there generally constructive. Do I have students who ever intend to become teachers may be one percent. Do they get a well-rounded sense of the nature of science just from my class, no; they get part of it; they get part of the foundation that they need. And they also take a bunch of other classes that hopefully you know sort of together help them, but I think that certainly my class along doesn't go any further." (Liam)

3.2.2. Design a course on the history of medicine

Don suggested a course on the history of medicine:

"… The course I have always dreamed of teaching, and I don't have the background to put it together in an easy way, which is one of the reasons I haven't done it, but it would be to take the history of medicine, which is you know total nonsense with huge successes.

And I think it is both very, very interesting and very, very enlightening to see that way which that worked. The way in which you know people created ideas out of their head because they liked some, which is total nonsense and harmed thousands possibly. Ah and the way in which solid research and verification tow things which are very valuable and it is a process which continues today. My own life this is as much as research on nutrition, because the nutritional research in the last decade has flipped back and forth and there are some notable failures. The hormone replacement therapy for example, which was thought and every woman on hormone therapy almost, was taken off the therapy, because it turned out that this do more harm then good. There have been a number of massive reverses like that based upon a, you know basically on a poor research strategy before implementing in the larger public as a whole. And this rush to approve medications quickly is also showing signs of negative you know further problems. And so the public not being educated in the way science works pit falls back and forth, the successes and the failures, the researching and advancing further again, you know you see this flip flop back and forth and all things just got out of hand, sort of nonsense. You know I can say that this characterizes my own life (laughter) and what can I do." (Don)

3.2.3. Design a course on religion versus science

Jack gave another suggestion. He proposed having a separate course that deals with the issues of religion versus science:

"Well, I think that originally; see I used to talk about this and particularly the Newton example, and particularly both of the Newton examples and I used to bring that up all the time. Well, you know I shouldn't say all the time; I used to bring it up once. And I always used to make the point that and I still would whenever a chance come up. I wouldn't make an issue out of it. See I don't want to make an issue in a science course if it is not science, and we have responsibility to teach things that are science, because those are the things we will test for, and that is what students should learn. Because they are going to need more courses that they take the things that they need professionally and there is not enough time as it is. However, that said I usually bring it up when I say if you get to the point where you want to understand where this force of gravity comes from, you can go over and ask some of the physicist if you will, and you goanna find out that they don't actually know, or you can go and you can talk to your favorite clergyman. And you will find that they will tell you exactly where it came from, but they won't be able to prove it and that is for another class. And I will leave it at that. But, I don't think that it is a bad thing for about as long as I just said (laughter). Was that a minute? That is as about as long for the entire 16 weeks 3 hours course that is about as long as much time I should devote to it. It should not enter the classroom any more then that. Now there could be, there should be a class that addresses this issue, because it is important. People are talking about it; people are trying to decide what to do. Some people feel very so deeply, some people very so against, but there are a lot of people who haven't made up their mind and they don't have the fact to have a reason for, you know to make up their own mind. Let's face it; in the best of the worlds people make up their own minds. They

don't get told what to do and at the end they rationalize, they talk to each other. Well, that is how it should be. So, I think there should be a course on that subject, the interface between science and religion specifically. And there should be very little discussion of religion in all the other science classes, like about I said about maybe two or three minutes in 48 hours, or and there should probably be almost no discussion of science in religious course, because I have nothing to do with it." (Jack)

3.3. Curriculum concerns

On this theme some participants called for getting students involved more with current literature. Another scientist proposed giving students wide breathe of information. Two more recommended improving K-12 science education and making students interested in science early on. Other three scientists called for improving K-12 science teachers' skills by introducing them to scientific research. Another participant questioned whether college education is career orientation or production of literate people.

3.3.1. Getting students involved with current literature

John, Tom, and Tina suggested getting students involved with current literature and introducing them to the necessary scientific vocabulary:

"Ah it really comes down to you know having them investigate the literature that is out there. One of the classes that we are implementing right now here at our university is a preceptor seminar course for all of our freshmen, and which I plan on teaching in a way that has students looking at articles that are written to their level, but are scientific articles. And so that they get to choose articles, they get to read them, and they get to dissect them for what were the questions that were being asked, what was the information that was found, what are the conclusions that are being made, what information wasn't included that you would like to know so that you could better understand this because it wasn't included in the article. And have them go to the other literature in the library or the Internet sources and say what is that information to the questions that I just asked based on the article I read. So it is really just getting them involved with current literature." (John)

"Ah well there is certainly, one of the things you know in my class is that vocabulary counts, you know even a very well written say article in "Science" magazine or "Scientific American" is still challenging for some students to understand simply because there are so many terms that they don't understand we talk about it and we simplify the terms. So you know, I think you have to give students that vocabulary, but I think you also should, I think they should start reading literature. You know there is a primary research literature, secondary literature for broader audiences both of those I think are value in their own way, and you know rather then making students learn everything just make sure that they have access to a way that it is, you know to find definitions or a word they don't understand. Ah but there is you know, there is information that are kind of you know third hand or fourth hand sources of information

> *that students see science that way as if it is just a collection of these conditions, you know sort of explanation are obtained from. So, I would advocate fostering more primary and secondary literature to introductory science course. You know, I think a lot of professors who think that their students are incapable of reading that stuff, so they goanna wait for the right time, but at least at a place like this Ivy League institution students are capable a lot. I think even if you put it out there and say you know I want you to read this and expect you to understand it, they can't you know it is just that they haven't really so far reach to that point. And you know I think, there is a lot to be gain from you know, if you want students to understand say cancer biology or something like that, you can have them read a chapter in the textbook about cancer and about the cell effect or something, or you can have them read a couple of well written review articles about cancer research or something like that and that probably will force to get all the information that would have been in the textbook in order to understand that review article. But they will see, I would guess that they would see the field differently, if they read more sort of primary and secondary literature instead of the textbook. So that you know, if I had complete freedom to design a course that is probably something I would do, may be not get rid of the textbook all together, but really use the textbook as a glossary to supplement or direct source of information."* (Tom)

> *"They have to know the words. Jargon is very important, so helping them to understand that science jargon is understandable will help them to become more literate so that they can read a science article in the newspaper, for example. A lot of it is just a language barrier."* (Tina)

3.3.2. Give students wide breathe of information

John also suggested that giving students wide breathe of information "will do a society a favor," because it "will educate them to become more responsible citizens when it comes to science":

> *"Ah it is giving them a wide breathe of information. I think we tend to specialize too much in the education of our students. Our students need not say, I want to learn one thing because this is what I like, they need to know about various things. Because number one they might not know what they like until they encounter it. But number two is that the nature of the world is that we are not training somebody with a bachelors of science necessarily to be a biologist for life. They have just a good a chance depending upon their abilities to work in any field in society outside of biology if they do in biology. And giving them a good breathe of all the different information, I think we will do a society a favor, because we will educate them and become more responsible citizens when it comes to science."* (John)

3.3.3. Improve K-12 science education and make students interested in science early on

Peter and Joel suggested improving K-12 science education by increasing the low standards in high school science and getting students interested early on:

> *"I - How do you think we can make them much more scientifically literate?*
> *P – Ah that (pause), you can potentially make them more scientifically aware, but making them more scientifically literate that I think requires them to do things on their own outside of the classroom, but there is, in this age, there is a large component of students that won't do that. Either because they don't want to or that they just don't see the value of it. I think that, that would be, that would be difficult to do once you are at this stage. I think it is something that you got to that you got to work on it as well as other. You got to try to in K-12 education brake down the wall of science phobia, which comes down to becoming very constructive basically. That probably would be very hard to match, because for every good instructor there is mediocre instructor. May be you could students do just fine enough process, may be the rest of the students, may be in terms of what things look like in paper that you know nothing changes, but the outcomes won't be very different if they do that. There is no way to, no way to regulate how people in education positions are up to that task. I see that once they get to college you can improve scientific literacy in people who have a genuine interest in improving their scientific literacy. I think basically at that point (in college level) to a large extent there is no a great deal of introduction to scientific literacy. People have their set views about their position in terms of science views. I think from my experience that would be a major, major hurdle like to try to get over things like that. I think that is something that you can only improve through improving earlier on."* (Peter)

> *"I – Do you think there will be any science teachers among them?*
> *P – It is possible, yeah there are two hindered and fifteen; there are a lot of science majors. Now this course in terms of science teaching is a, (pause) in high school they kind of drop the level required for engineering, for example especially freshman and sophomores but in case of graduate level, I think that need certain level of science teaching probably lowering high school than it should be…. On the other hand I think that there is a good teaching in high school today, but the level is lower then how it should be. I don't know what science education courses science requirements are, but in high school they aren't particularly high."* (Joel)

3.3.4. Improve K-12 science teachers' skills by introducing them to scientific research

Lena, Don, and Frank proposed improving K-12 science teachers' skills by introducing them to some kind of scientific research, and suggested that teachers, especially teachers placed in the elementary and the middle school, must be knowledgeable in their subject area. Furthermore, Don pointed out to the change in culture towards science in American society:

"Hum, yeah again, I guess I just want them to kind of get a sense for how do recognize scientific and nonscientific arguments. Give them a sense of how science is actually done, you know, what the people do; what is involved in the process, the peer review is important thing for example and just the mechanics of doing particular studies, you know, just give them a flavor for it. They can sort of see where it is coming from that it is not just stuff that we made up (laughter). But, you know there is a lot of data behind it and a lot of thought goes into it. Ah (pause) ay, ay, ay, I don't know, ah (pause) I think that, I think that people that are teaching science at grade school levels or high school levels, they had to have a little bit of experience of doing it at some point, you just can't get it out of a book per say, I don't think, you know. I mean, I am not saying that they have to be a scientist, or had a PhD in, you know physics or something like that, but I think that if they had some experience at some point, somewhere along the line and doing something it helps, you know. Ah, and I think if you have particularly creative people that can come up with some question driven ways of teaching particular subjects as opposed to just rote memorization, memorizing the stuff in the book you know that is the way it is. If you can sort of do it in terms of active exercises and trying to, you know, basically to discover and process; doing it yourself to learn it and I think that really helps. Ah (pause and laughter) it is a though skill, I think, you know, there are few people that are really good at doing that, but boy you really know when you meet someone." (Lena)

"I – Any final thoughts?
P – No, very interesting questions. Final thought yeah, I have one. Get the grade school teachers involved in getting their students knowledgeable in a deeper level and you know I don't know how to do this, so I don't have position quite how I would do that, but I have a sense, I could be wrong on this, but I have sense that a lot of presentations of science at the lower levels is kind of going around looking "oh here is the bird, this is a different kind of bird, look at that bird, here are the names of the birds" you know here there is a plant and etcetera like that. I mean and let's make a garden, kind of geophysics sorts of stuff. And I don't know how at what levels, what age levels it is appropriate to do what sorts of things, but I have the feeling that students ought to come out of the middle school may be more knowledgeable then they are. I am not so sure about (pause), about the understanding of the way in which science works, I know it is difficult and I started thinking about these things I kind of keep learning whether the cultural issues. You know when I grew up the culture was interested in science; on TV at the end of a commercial you know better living through chemistry. I think that was General Electric or something like that amongst that or anyone. And the space program was just breaking and it was part of the culture, universal almost to be interested in that, you couldn't avoid it. And so, kids like me got sucked into it and the culture is a different now. And the kinds of goals, which I think are important for personal development, public policy, kind of go against the grain of the culture we are in right now. And that is probably not a good thing. I am little bit to far how to address it; basically it is a war, which we lost, may be some thirty years ago, I am not too sure. But you know stuff just changes, but anyway if, I think that is where the battle needs to be played, the battle needs to be played out at the

elementary and middle school level, you know it has to do with boards of education and principals of high school and the teachers in the frontline so to speak. And try to produce an enlightened society that constitutes kind of an underlying society." (Don)

"Oh final thoughts. Ah (pause) I think there needs to be more, ah I don't, I am not certain how much, it is a great question about you know how much science the people need to know and how much mathematics people need to know and I am not certain I know the answer to that. But teachers need to be well trained and I think that with teachers there is no substitution for knowledge. It is not enough to be a good teacher, but at least it is the bare minimum, if you don't know the subject how can you teach it and you got to have more then that, you got to have the flair, and the technique, and all that stuff, but boy if you don't have the knowledge to teach then you are in the wrong field. And unfortunately a lot of teachers have been placed in the elementary and the middle school, and to some degree in the high school in position where they don't know what they are doing and they have been forced into it through circumstances and it is too bad. So, I like to think that I am trying to help that out. I like to reach out to more teachers actually. I think we should have workshops here for teachers and specific short little workshops during the summer that teachers could come into for like three or four days and get a big shot of astronomy or big shot of meteorology or some of that." (Frank)

3.3.5. Whether college education is career orientation or production of literate people

Liam raised the question of deciding whether college education is career orientation or production of literate people:

"The reason I hesitated ah you know is (pause) I think that in general we have to decide whether college level education is career orientation or it is intended to produce educated in life people. Ah students, most of my students, generally come into the class wanting to learn something primarily about the specific content. They want to be told the facts and they want to leave the class having mastered a bunch of facts. Ah, and they you know are career oriented in doing this, they want to know the things that they need to know to be a nurse, or to be a physician assistant, or to be a pharmacists, or whatever it is they are planning on doing, and are not so interested in learning about the ideas of what the nature of science is. And so I guess, as we sit down and think about what the design of the class should be, what are the issues that we should grapple with, how much of what we are doing is providing students with 'will I get to be able to work' education and how much of it is teaching them their specific career relevant material." (Liam)

3.4. Making science interesting and attractive

Five participants called for stirring up students' interest in science and three called for making science interesting and attractive to students

3.4.1. Make science interesting and attractive to students

Lena, Jack, and Don called for making science interesting and attractive to students:

> *"I – How do you think we can make students more aware of how science works?*
> *P – Hum, hum, by pointing out how science works and I don't mean the technological development, but the project of science. Science comes up in every day life for everything. If you point out for somebody he adores, you know if a woman finds a guy attractive she will figure out where that guy is and vise verse. And they do it by very clever means. People can be scientific if they want to be as long as they are attracted to it. And you can find examples like that I just picked that one very quickly, but there are lots of examples like that. If a woman sees another woman with very attractive blouse she will find a way to figure out where she got that blouse. Some times it is just going over and asking her. Some times it is like checking and seeing where she shops and things like that, but they will find out. You know, some of these examples are not particularly good example, but you can try and find examples in scientific and objective manner in all kinds of context. And I try to find those, but those are only I see. Mostly only come up in a for non-science majors type course, but of course if it is a technically oriented course the content, the context of the content are more then enough to keep the focus on what is science, what is not science, and how to think scientifically, because if you focus on it, you know, you don't want to, you just want to do problems that is the nature of chemistry; teaching chemistry is doing problems of all kinds as much as possible."* (Jack)

> *"I – How do you think we can make students more aware of how science works?*
> *P – (long pause) Hum, take away their video games (big laughter), turn off the television (laughingly). They can go outside and look around. Ah, I don't know, Ah (throat clearing) it is a good question. Ah (pause) yeah, I don't know, I mean, I know that there are people out there trying to devise new curricula for non majors. You know, to try and get people interested in the sciences, not so much as a career choice per say, but just to get them scientifically literate, you know. And I think, efforts like that are really important. Ah, and I think, often times it doesn't fall under sort of traditional discipline lines, and so people don't do it as much. So they end up teaching a class, and I like mine, it is a standard rocks for jokes class. You know, you cover the standard material, you know, but I think there are ways of incorporating things that are little bit more relevant to the average person into some of these classes that makes them more accessible and may be makes them little bit more interesting and gave people sort of thinking little bit more about things. So I think if you goanna do little of that it helps."* (Lena)

> *"Ah I would like to have more time with them. It is the first thing that comes to mind, but the most important thing probably is I think you really, really need to have a course which the students can relate to. And to amplify on that the traditional physical science courses teach, is taught by a physicist, it starts of with kinematics equations, you know you drop rocks, you throw cannonballs trough the air stuff like that. I don't think that the typical student these days is kind of seeing those as deeply interesting, they don't draw*

the students to them so to speak and so you can course them in the learning the formulas and giving you the answers they want, but you know that doesn't really get to the deeper issues at all. And the same thing if you carry that procedure, you know through the, we are talking about electromagnetic field etcetera like that, I am thinking of the conceptual level here not the mathematical, science major, physics major, this kind of a course. So that I think is the poor context in which they try to make people aware of science. In principle they should work very, very fine, but in practical I don't think it does, because of lack of student meaningfully relate to it deeply. That is one of the reasons I like my hypothetical medical science course, because I think almost everybody is interested in their body and how it works, and medicine, and nutrition, and gets a lot of attention lately, and I don't know if the students follow the News Medias carefully as adults do, as I do for example, but one can see lots of things there, which would attract attention, everything from a magnetic bands, and heat pats, and acupuncture you know all bunch of stuff, and evaluating nutrition, and recent nutritional guidelines and stuff like that, and the effects on long term health and stuff like that. They all coming out of the history of the medicine, I think that has a possibility for drama partly because it is you know blood and disaster, you know it is typical style in which modern media you know catch a picture of a lion in a nature story pulling down a gazelle or something like that and eating it, you know you can draw big audiences. You can do that with history on medicine, you can see if you can take an advantage of that particular aspect of human psychology (laughingly) to better purposes may be. A course, which in the past I used in exactly that way and I liked very much, is the cosmology course, because again you had the historical perspective and you had the interplay between science and religion, you had the role of imagination and speculation and technology, and it dealt with larger issues the nature of the universe, you know the ultimate questions so to speak of where we came from and where we are going at least in physical sense it is not necessarily in the theological sense. And I thought that to be a kind of a grouping context and I think that works very well, but I don't think it works now as much as it used to. And I have a sense that people, the students that I deal with, have been dealing with, in this particular course, in this particular school that I teach in, are more centered on the here and now and less interested in the greater larger questions so to speak. And the other thing, which they are into is exemplified by a young student who, I think I said something about the planets, we haven't even got to the stars yet, and she said "the Lord put them in place" as if that was in a story (big laughter) and I don't know that I ever broke into her (laughingly). So again you see the idea in cosmology in the historical perspective things like that. And I think that doesn't work as well and I would try to go to something more immediate in biology in medicine, the current issues in front of us I think via context in which I would like to work. I don't have quite the background for the medicine, environmental science. Ah I would like to do something with you know DNA in molecular biology and that is something which a physical scientist I think can easily get into which has implications for contemporary policy and the complications with religion and things like that, but you always thing of species as just machines and I don't think that is a point that is well appreciated. There are actually some magnetic machines like *the thinker toys, they pull each other into these various different configurations which makes something else happens etcetera, etcetera you know. And so, you can go from purely mechanical situation and work your way all down into these interesting theological, philosophical, public policy interests and this is beautiful history, the discovery behind it. And I think that has a potential for a course you know, if I was a young teacher starting my career probably will be the certain direction, which I will begin."* (Don)

3.4.2. Stir up students' interest

Josh, Rich, Jack, Max and Donna called for stirring up students' interest. This recommendation was in support of the calls of Lena, Jack, and Don for making science interesting and attractive to students to make them understand how science works:

"I - How do you think we can make students more scientifically literate people?
P – Scientifically literate! Ah (pause) I think it is important to stir up an interest. The things that I had privilege to teach and it is about ability and I had been very fortunate to teach about, but there are of a lot distractions and electronics contributed to that, but you know if you can get their interest and show them that something is exciting, you know that is how to deal with the problem…." (Josh)

"Well, I think one has to get them interested and then also to have a feeling that they will decide and so that they can form some, they can form an informed opinion about science. But, I think that one first has to get them interested as I mentioned to picking up cases from everyday life or literature." (Rich)

"Scientifically literate! Hum, paying them to read (big laughter). They are not interested. Ah, other then making them more relevant, you know, making them to see the relevance. You see that is the problem; exactly how to make them see the relevance becomes the same question. For some people they are not going to, and you know it is fine. They are going to think about things that we don't want to think about, but that somebody should think about. So not everybody needs to think about science, I mean everybody needs some preaching, because it is important they talk about things, get the recourse we need to do what we want to do. Science has a big effect on people's lives, but other then trying to make that point over and over aging I don't think that there is anything that we can do." (Jack)

"Ah (pause), one of the things that is major stumbling block for several classes is mathematics. They are very reluctant to take mathematics and that makes very hard to do science. I think that the best you can do is increase their interest in science and hope that they will go on reading about science after this course. Some students are involved in journalism and you may hope that they will choose scientific journalism. There are a lot of scientific writings in this course and sometimes I give them reading." (Max)

"Oh man (long pause) I wish I knew. Ah I think trying to incorporate the examples of what is going on in you know kind of it is wider culture now in explaining how this has any scientific bases is a way of engaging students interests and getting them to think about issues in a scientific way rather then operating on the bases of received knowledge." (Donna)

4. Conclusion

Data from the questions that sought to explicate scientists' recommendations for improvement in teaching of science reveal that scientists called for use of active teaching methods such as, teaching science in laboratories to give students a chance for more hands on activities and solving real research questions and where they can learn science by "doing science", teaching the basics of science, giving students critical thinking skills, incorporation of group work, and case studies in instruction. Furthermore, they recommended class on history of science, history of medicine, and course on science versus religion. Also, few raised some curriculum problems such as, getting students involved with current literature, giving students wide breathe of information, improving K-12 science education by improving teachers' skills and by making students interested in science early on, and one questioned whether college education is career orientation or production of literate people. Additionally, few scientists proposed making science interesting and attractive to students by stirring up their interest and by making students feel comfortable asking questions. In addition, one scientist called for having students gain some "fundamental basic math skills", and making "sure you have people teaching the classes that they want to teach."

Findings of this study support the science educators (Abd-El-Khalick, & Lederman, 2000; Duschl, 1985; Lederman, 1992, Irez, 2006; Karakas, 2006, 2008; Kimball, 1967, 1968; Saunders, 1955; Schwartz, 2004) in their advocacy for improved student understanding of NOS. Moreover, findings call for increasing the scientific literacy among freshmen students, which is in line with some science organizations' calls (AAAS, 1989; NSTA, 1982; NRC, 1996). Scientists in this study also assume that an understanding of NOS will enable student to be more informed consumers of science so they can make informed decisions when confronted with scientific issues.

This study also tried to help science instructors reflect on their teaching as it was recommended by some researchers (Dewey, 1933; Eby & Kujawa, 1994; Lee, 2005; Kember et al., 2000; Mezirow, 1991; Pugach & Johnson, 1990; Richardson, 1990; Rodgers, 2002; Schon, 1987; Sparks-Langer & Colton, 1991; Taggart, 1996; Valli, 1992). Through the reflective process, the aim was to develop effective teaching habits in the instructors.

Moreover, the findings of this study confirms that both personal characteristics and teaching methods seem to be important (Demmon-Berger, 1986; Tobin & Fraser, 1990; Treagust, 1991; Fisher, et. al., 1993; Wubbels & Levy, 1993; Czerniak & Shriver, 1994; Cotton, 1995; Gresh, 1995; Fisher & Rickards, 1997; Norton, 1997; Rawnsley & Fisher, 1997; Atwater, 2000; Witcher, et. al., 2001; Aagaard & Skidmore, 2002; Waldrip &

Fisher, 2003; Davis & Smithey, 2009; Cone, 2012; Fitzgerald, et. al., 2013; Karakas, 2013; Olson, et. al., 2016) in teaching effectively science to freshmen students. The instructors in this study also 'have high expectations, and push students to succeed, they trust and respect students and recognize them as individuals, while building on their strengths … they are confident in their own teaching practices and believe that all students can learn and thus are persistent and resilient, even in the face of obstacles' (Cone, 2012, p. 892).

Most importantly, this study also points out the importance of active learning and teaching (Coffey, et. al., 2011; Hammer & van Zee, 2006; Roth, et. al., 2011; Russ, et. al., 2009; Talanquer, et. al., 2012) and calls for teaching science in labs by doing science, use of group work and case studies in teaching science to freshmen students, and giving students critical thinking skills.

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Appendix A

In my interviews I asked my participants questions, such as the following:
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 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 see scientists do science?
What goals do you have for your students?
What do you want your students to know about science?
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 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 them probing questions during the interviews when I saw it as necessary. Probing questions such as: Can you elaborate more on the issue? How exactly is that? What do you mean by that? Can you explain?