BECOMING A SCIENTIST: VIEWS OF FEW SCIENTISTS

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Abstract. This study examined experiences of science faculty who teach introductory undergraduate science courses including the fields of chemistry, biology, physics, and earth science. Participants were seventeen science instructors from five different institutions in the northeastern U.S. and all of them were interviewed. Findings revealed that participants generally had a public schooling experience. Their interest in science generally started as self-motivated and self-interest in middle and high school years, except for the three female scientists who got interested in science in their college years. Their parents were generally college graduates and supported them in their education in general, but did not give them any particular guidance in getting into their field of science. Most of the participants described their best science teachers as being, enthusiastic and exciting about their subject, motivating and involved with their students, and as a person who uses a lot of demonstrations and hands-on experiments. The participants were interested with general social issues in science, such as evolution vs. creationism and stem cell controversy. The majority of the scientists said that they understood how science really works in graduate or after graduate school.

Keywords: science education, becoming a scientist, interest in science, scientists' schooling

Introduction

The history of the advocacy for teaching science, nature of science (NOS) and increased scientific literacy in science classrooms is evidenced by the National Society for the Study of Education, NSSE (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 clearly stated the most recent objectives of science education with the following statement:

> [S]cience 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).

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 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 history, philosophy and the workings of science not only in their pre-service science methods courses, but also in their undergraduate science courses. Having in-

structors who understand the workings of science in their early introductory level science courses becomes important. Furthermore, figuring out how these science faculties become aware of the workings of science might be important too, so that they can address these issues in their teaching.

Clearly, science educators (Abd-El-Khalick & Lederman, 2000; Duschl, 1985; Lederman, 1992, Irez, 2006; Karakas, 2006; 2008; Schwartz, 2004) and scientists have been persistent in their advocacy for improved student understanding of NOS over the past several decades. Kimball (1967) 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).

In line with this advocacy, the present study investigates how 17 science faculty who teach introductory level undergraduate science courses including the fields of chemistry, physics, and earth science were schooled about science and NOS in their schools and were supported by their families in pursuing a science career. This information will help us to better understand the educational experiences of scientists who teach introductory science courses to undergraduates in our universities. This study aims to provide a deeper understanding of the extent to which science professors were taught about the aspects of the history, philosophy and sociology of science in their elementary, middle, high, undergraduate and graduate schools.

Additionally, how we teach is determined largely by how we learn best and how we are taught. Thus, having the example of science faculty who were taught in line with NOS objectives might help scientists to learn the techniques for teaching NOS. Moreover, having science instructors who teach in accordance with NOS objectives would help science educators attain the National Science Foundation (NSF)'s call for more inclusive undergraduate science

education, one that makes science interesting, understandable, and more relevant to all students. The NSF argues that

> [A]ll students [must] have access to supportive, excellent undergraduate education in science, mathematics, engineering, and technology (SME&T), and all students [must] learn these subjects by direct experience with the methods and processes of inquiry. America's undergraduates – all of them – must attain a higher level of competence in science, mathematics, engineering, and technology. America's institutions of higher education must expect all students to learn more SME&T, must no longer see study in these fields solely as narrow preparation for one specified career, but must accept them as important to every student. America's SME&T faculty must actively engage those students preparing to become K-12 teachers; technicians; professional scientists, mathematicians, or engineers; business or public leaders; and other types of "knowledge workers" and knowledgeable citizens (NSF, 1996).

However, simply understanding how science works in not enough for students, as Magolda (2004) argues in her research, students should move from simplistic understanding of science to more complex understanding of science. She points four categories of intellectual development form simplistic to complex thinking: from absolute knowing (where students understand knowledge to be certain and view it as residing in an outside authority), to transitional knowing (where students believe that some knowledge is less than absolute and focus on finding ways to search for truth), then to independent knowing (where students believe that most knowledge is less than absolute and individuals can think for themselves), and lastly to contextual knowing (where knowledge is shaped by the context in which it is situated and its veracity is debated according to its context). Discovering how a scientist became interest-

ed in science may assist in the discovery of when they understood the complex understanding of science. Few studies reported that undergraduate research experiences "are clearly successful in enhancing a number of basic scientific skills, the evidence is less compelling that these experiences are particularly successful in promoting the acquisition of higher-order inquiry skills that underline the foundation of critical, scientific thinking'' (Kardash, 2000; Hunter et al., 2006).

The questions and concerns discussed above form the foundation of this study. Furthermore, the theoretical framework that guided this research is based on the works of several research studies and summaries of research. The summaries of research by Lederman (1992) and Abd-El-Khalick & Lederman (2000), and research studies by Durkee & Cossman (1976), Glasson & Bentley (2000), Irez (2006), Kardash (2000), Karakas (2006; 2008), Kimball (1967), Pomeroy (1993), Schwartz (2004) and Hunter et al. (2006) contributed in developing working conceptions of beliefs for this study. These studies argue that teachers cannot be expected to teach about NOS if they do not really understand NOS, and that simply possessing the necessary knowledge about NOS does not guarantee its effective communication to students. The purpose of this study is to find out scientists' educational experiences and family backgrounds in order to see how they get interested in science and how we can make our schools more interesting for students in the area of science.

Methodology

Participants

Seventeen participants comprised the sample for this study. 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 U.S. E-mails were sent to total of 30 science faculty members who taught introductory chemistry, phys-

ics, 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. These participants were part of a larger study (Karakas, 2006; 2008; 2018). Interview times were arranged according to participants' schedules. The most commonly stated reason for not participating in the study was time constraints. Depending on the institution they came from few participants were practicing scientists, and majority had done some research, but mainly were concentrated on teaching. One in-depth individual interview with each of the participants was conducted during the fall semester of 2004 and spring semester of 2005. The interview times ranged between 15 minutes and 1 hour, the average interview time was 30 minutes. All participants in the study were given pseudonyms in order to keep their identity anonymous. All the interviews were conducted in person in each scientist's office, except one, Don, who came to researcher's office. All of the interviews were conducted in a single session. Institutional Review Board of researcher's university provided the necessary approval to conduct the research. 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

Data collection

This study employed qualitative methods, and particularly an 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). As such, by using this research design and utilizing in-depth interviews, study explored the ‘culture-sharing’ behaviors, beliefs, and language among college science faculty. Study focused on science professors’ schooling and parenting experiences. In-depth/open-ended nature of interviews, as Bogdan & Biklen (1998) write, “allows the subjects to answer from their own frame of reference rather than from one structured by prearranged questions” (p.3). Also, the study used loosely structured interview guides (Appendix A), as recommended by Bogdan & Biklen (1998), in order to “get the subjects to freely express their thoughts around particular topics” (p.3). In the study this topic was early experiences with science. The researcher developed the loosely structured interview questions used in this study. Interviews were recorded on a digital voice recorded and later transferred to computer. The study was part of a larger study conducted by Karakas (2006; 2008; 2018).

Data analysis

Present study used qualitative methods in analysis of data. Interviews were transcribed in the summer of 2005 and later coded according to emerging themes. First step in the analysis was data organization procedures recommended by Bogdan & Biklen (1998). In organizing the data, the researcher 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 & Biklen (1998), 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, 1998). For example, while reading a transcript the researcher coded certain views as schooling type, teaching experience, first in-

terest in science, parental support, parental guidance, best science teachers, reading interests, controversies followed, and etc., in average there were identified more then 30 codes for each participant. Later on these codes were collapsed into categories such as, schooling type, teaching experience, first interest in science, parental support and guidance, best science teachers, reading interests, scientific controversies followed and etc.

In this study, a realist mode was used to represent the participants' views through closely edited quotations and interpretations of those quotations (Creswell, 2002; Van Maanen, 1988). Thus, the researcher lets the participants share their thoughts. On the other hand, the researcher shares Roth & 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, informants' "talk reflects the communities and language games in which they participate, for there are no private languages" (Roth & Lucas, 1997). Thus, the researcher makes no claims that the data gathered represents informants' permanent and deep-seated views; rather he reads them as socially constructed in the moment. While 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, the researcher's "biography, politics, and relationships become part of the fabric of the field" (Bell, 1993). Although the researcher leads the reader what meaning to make from participants' quotations, he tried 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 that of the researcher. Results are presented as a description of emergent themes that were developed through the analysis. Interviews were coded and collapsed into categories.

Limitations of the study

There are several limitations of this research. First, the sample was one of volunteers. These individuals are not necessarily representative of other scientists within their broad disciplines, sub-disciplines, or specialty areas. Therefore, the results are limited to this group of scientists and caution should be exercised when attempting to infer about any of the results with regard to other populations. Second, the researcher was the main instrument of data analysis. The analyses and results are a product of the researcher's interpretation of the data. The interpretation was based on the researcher's knowledge and experience in science and science education and his social location. Therefore, the theory-laden nature of the investigation is a recognized limitation as well as its strength. An exploratory study is the product of the researcher's perspective, and it is recognized that a different researcher may identify different features of importance within the same data sets (Bogdan & Biklen, 1998; Creswell, 2002). Another limitation was the limited number of participants. Thus, these data are only indicative of the type of institution setting in which faculties worked.

Results

The themes that emerged from the interview transcripts were as follows: participants' schooling type, level of experience in teaching in college, how the interest in science started, what kind of parental support and guidance they received in getting into science, describes the best science teachers they encountered through their K-16 education, their reading interests, and what kind of scientific controversies they followed throughout their career.

Schooling type

Almost all of the participants had public K-12 schooling experience all over the continental U.S. Two participants, Frank and John, had both private and public schooling experience, only Chris had a private school experience

through K-12 in Spain, Max was from New Zealand, but he went to public schools:

> "I – Where did you go for elementary, middle and high school?
>
> P– I went to elementary school at X School here in the city, no longer existing turned down. And starting in the fifth grade all the way through graduation from high school, I went to a little private school in D… It was initially called Z School and now is called W School." (Frank)

> "I – Where did you go for elementary, middle and high school?
>
> P – I went to elementary and middle school was a catholic school in N… F… and high school was a high school in B…, NY.
>
> I – So catholic school was private schools?
>
> P – Catholic school was private school. I went to catholic school from kindergarten until tenth grade and then I did eleventh and twelfth grade in public schools." (John)

These findings show that public schools, although they receive less money then private school in U.S., can still graduate students who are interested in science and who choose one of the science disciplines as their profession.

Teaching experience

Six of the participants had 1 to 5 years of teaching experience, two of whom were female. Three participants had 6 to14 years of teaching experience and two of them were female. Eight participants had 15 to 40 years of teaching experience and none of them were female. These findings show that the entrance of women into sciences starts late after the 80's and this reveals that there was gender inequality in getting into the sciences even in the booming times of science in American society, the 1960's, the Sputnik era.

First interest in science

Only one female participant, Lena, reported very early and self interest in science, before elementary school:

"I- So what interested you in science?

P – Oh god, it just always has been, it just, ever since I was a little kid, I always been interested in it (saying it while laughing) so there is no particular person that ever got me into it.

I- So it was in middle school or elementary **…** (interruption by the interviewee)**?**

P – No, way before that. I was little tiny kid (big laughter)." (Lena)

The other three female participants reported very late interest in science, freshmen years in college:

"I- So what interested you in science?

P – To me science was the most challenging set of big topics, so I found them interesting, cause, they were the hardest things to me to think about.

I – When did you started, when was the sparkle, you know in the middle school, or elementary school?

P – In college, that is when I decided to pursue science." (Tina)

"I – At what level you can say that the sparkle started?

P– Probably in high school, ah I remember liking the sciences, but more so probably in college I decided that is really what I wanted to do. In high school I don't think anyone knows what they wanted to do. Very few people do, but if you can do God bless him, but I didn't

have a clue. So, probably somewhere in high school I knew that I liked the nature of the sciences, but it wasn't until college that I realized how much they appeal to me." (Pat)

"P– I enjoyed all of my classes mostly up through high school and into college, but I began focusing mostly on science in college rather then earlier. I considered ah majors in history and economics as well as the natural sciences as an undergraduate." (Donna)

Although, the number of female scientist was small in this research and it is hard to draw generalizing conclusions, these findings show that K -12 science education is still unattractive and uninterested to female students, female students cannot relate to science until they attend college. Science educators should recognize that there is still gender problem in science education, and to overcome this problem they should develop science courses that are relevant to female students too. This could be achieved by incorporating everyday examples into the science topics that can appeal to all students.

Ten of the male participants reported first interest in science in late elementary and in the beginning of middle school. They all also reported self interest and self motivation in going into science:

"I- What interested you in science?

P – Oh, it is a good question.…. And so, what interested me in science really goes back to more middle school and you know if I hat to think about it I am not quite sure how that come about, I read all the books about the atom in the library when I was in sixth grade, small library, but persistent reading and interest in. And I guess I was interested in kind of how things work. I put together a simple door bell and battery, when I was back in sixth grade, you press it and our

own door bell rang, you know big deal but it was something putting together." (Ron)

"Ah, I think at the most basic level the thing that interested me in science was just that I had lots of questions about the world; you know as a kid I was spending a lot of time outside, hiking and playing and doing stuff and my parents introduced me, you know, to explore and ask questions. I guess science is the way it is; at least it is the way that I decided that if you answered those questions or figure out the answers, so I guess what draw me to it, through my sort of curiosity about the nature." (Tom)

"Oh, when I was a kid I use to be one of those interested in the development of quantum theory, you know of the history of physics. That is what got me into science." (Max)

"Ah (pause) I guess how I became interested in science was in my junior high school. I decided that in biology there were many interesting things, particularly in lab and what I get out of this was of course very new for someone very interested in science, was real science, biology. I think it has to do something with functions of organisms then the other sciences do." (Liam)

Three of the male participants, John, Frank, Chris, reported interest in science in high school. Frank and Chris reported self interest; John sited teacher influence on getting interested in science:

"I- So what interested you in science?

P – Well, it is difficult to explain. Just the questions I think interested me in science.

I – When did you started, when was the sparkle, you know in the middle school, or elementary school?

P – High school. Well I was always interested; I mean that is when I decided to do it as a career." (Chris)

"P – I was kind of interested in high school, but my interest in science didn't really crystallize until my high school physics course and then it took like two or three lectures and that was it. I knew this is the course." (Frank)

"Ah**,** I had a biology high school teacher that I thought was fantastic and it ah all snowballed from there." (John)

Parental support and guidance

Ten of the participants expressed that their parents were college graduates and had supported them in their education in general, but did not give them any particular guidance in getting into their field of science:

"I- So how did your family affected you in pursuing science?

P – Ah, my dad was an engineer and had a lot of scientific background and so he was very logical, I guess, and very mathematical. So sure that was helpful, sort of watch his line of thought his logic, his thought process that was good for me. Ah, my mom was in the medical profession and so and also very interested in natural history and general science. So we always had stuff going on, she will bring home a cow hard to dissect or some strange thing like that, you know, we were always into doing stuff, you know, but as far as Earth science and geology that was just me into it." (Lena)

“I- How much your family had effected in you choosing science?

P – Ah, well it is actually interesting. Both of my parents are artists, but they are both teachers. So, my mother is a painter and a college professor teaching painting and graphic design and my father is a sculptor and has on and off taught at the university level. And so, you know, people are often surprised that the scientist they see is a son of two artists, but I think, growing up in household where both parents are artists I got the message and my older brother who is an engineer, we both got the message that art is something you can value, but may be not a career choice (laughter). So, you know, may be the economic struggles that our parents went through, raising us, and putting us through college convinced both of us that something like science or engineering would be better, more stable economic alternative I suppose (laughingly), but you know, I think my, so there is that influence as far as make me choosing a subject of study, but I think the fact that I end up at teaching is definitely in large part comes from my parents. Ah, you know, education is, education for education’s sake not necessarily for a career goal or something, it was a something that was valued in our family, you know, so even though teaching isn’t the career where you goanna get rich, it was something that I thought it was worth doing.” (Tom)

“P – My family! My father was a grad student in physics and switched to engineering in Second World War and stayed in engineering. My mother had plenty of artistic bend, which never developed in any professional way. She was the one who got me interested in birds. My father was very supportive too, taking me on trips, and also he was a scholarly person, he read a lot, he knew about all sorts of things. Anyway, he had massive books you know one of the things

that really helped me was there were a lot of choices. I mean if I got interested in something, if I really wanted a book I got it, you know within reason of course, but you know if I can come up with good reasons in wanting something, he would buy it." (Josh)

"I- How was your family effective in your pursuing science?

P – Hum, well (pause).

I – Did they encourage you or?

P – Yes, they encouraged me, although I think my parents would have liked both my sister and me to go into fields that were a little bit better finically. My parents are both well educated, but ended up in you know fairly profitable careers, whereas my sister and I both ended up teaching at small undergraduate liberal arts colleges and not making whole a lot of money." (Donna)

Five participants reported having parents who were high school graduates and having received little or no support or guidance from their parents.

"I- How did your family effected you in pursuing science?

P – Not really positively or negatively. My family, my parents really raised all of us, I also have two brothers and a sister, to believe we can do anything we wanted to do. Ah my father never finished high school. He got a GED years later. My mom finished high school and that was it. And yet you look at that and you think well more then likely the kids are not goanna end up going to graduate school, because it is hard without that example. And yet, I always believed my parents raised all us to believe you can do whatever you want do. So it was never like oh I can't go to college, oh I can't go to a graduate school, which is kind of interesting considering you couldn't bring your homework home to them and have them help you, you know

when you are doing you know some of the higher high school math and some of the science courses they weren't very helpful with that. But at the same time they were never discouraging of it." (Pat)

"I- How did your family effected you in pursuing science?

P- Ah, I was a first of three children to go to college. And really the only of, neither of my parents gone to college, very few of my relatives had gone to college that I had much of a help in terms of my family thing "oh this is something that you need to do", basically talking about study science for them was very abstract. And I think that there were some concerns, the usual things that I will be able to get good job doing this sort of thing, but that was never my career concern. I assumed that if I know what I was doing and that I do well the things will work out, which in retrospect is a little bit true nowadays, but that was the way they thought." (Peter)

"I- How did your family effected you in pursuing science?

P – My family, well may father and mother were not scientists, but did not really care what their children pursued in college and I decided science is the best.

I – Did they have college degrees or not?

P – No, my parents have a high school degree." (Tina)

"I -What was your parents' educational level?

P – My father was high school graduate and he was a builder, he worked in construction business. My mother left school when she was 12 years old. She lost her father when she was a child and she lost her mother when she was 12 years old, and so she had to leave school and take care of her younger brothers. So, she even didn't finish high school…" (Max)

One participant, Rich, had an immigrant family and said that they were supportive, but pushy towards medicine or engineering:

> "I- How did your family effected you in pursuing science?
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> R – They were very encouraging, though they were little pushy toward medicine, but in general they were concerned as emigrant families are about, especially having survived the war in Europe at least some of us being from Jewish minority group they were concerned about one has a profession that was portable and so medicine or engineering were really attractive to them and but science was fine, very supportive of learning on general." (Rich)

Another participant, Don, had a college educated single mother and said that the culture at time he was a kid affected him going into science more so then a parental support:

> "I- How did your family effected you in pursuing science?
>
> P – Ah (long pause).
>
> I – Did they have any impact on you choosing science?
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> P – Not really, I don't think that the family was in particularly influence, except indirectly in the era in which I was brought up. I am thinking of the 1940's, science and technological advance was part of the culture. So I think there are a lot of kids like me who played with radios and had chemistry sets, had electronic sets. So the family encouraged that, but it wasn't the effect of the family it was part of the culture in which family was influenced. And I am thinking of, I think it is a little bit different now, we see some of that in computers, you have students who are interested, young many people in computers,

but young people in my days had cars, and chemistry sets, and electric sets and things like that.

I – What was their level of education, your parents' level of education?

P – Ah my mother at the time, my mother she had a bachelor degree, but at the time I was growing up she was a college drop out. But a very intelligent women and she had a professional career, she was a meteorologist at that time, which is government meteorology. There was no father in the family." (Don)

Best science teacher qualities

Most of the participants described their best science teachers as being knowledgeable, organized, exciting, enthusiastic about their subject, motivating and involved with their students, person who uses different examples and analogies to explain a concept in a simple way, uses a lot of demonstrations and hands on experiments, and funny and entertaining. Here are some examples from the interview excerpts:

"I- So what do you think were their common like qualities that makes them good teachers?

P – Well in all cases, ah (pause) in all cases there was, well everybody was enthusiastic; there is no substitute for somebody who is excited about what they are doing. If they don't think it is interesting no one will think it is interesting. And they can make you think that what they do is interesting and that is important. And then there is they think it is important. You want something that is interesting and one who cares. The other thing is the importance and they make you think this is important, you know it will have an effect on your life, I don't expect in everybody's life. It will be something that you will be able to use and make money with later…. And I don't know what it

was that got across, because he was very soft spoken, he didn't go real fast, and didn't try to stuff an enormous amount of material, he picks what he thought was the most important thing and try to make sure everybody got that, because if they got that they can figure everything else out and that made a big difference…." (Jack)

"I – Looking back at your high school or middle school years how would you describe the best science teacher you had?

P – (long pause) I guess I would describe my best science teacher as someone who was little bit eccentric, expressed an infectious enthusiasm for organism and their interactions.… I guess the best qualities were their (pause) enthusiasm certainly, but also interest in interacting with students one on one and trying to get across a sense of the mechanisms by which these organisms work and how one can tell them apart and how they interact upon another." (Dona)

"P – Ah (little pause), I would say that the best science teachers that I had at that level, they were good teachers, because they nurtured my interest in the subject and emphasized sort of what was exiting and interesting about science and especially about the life sciences or the natural world and encouraged, you know, their students to get out and actually explore science for themselves whether that was through lab experiment, or through field trips or that sort of thing. I guess I have always felt that there is no substitute for actually doing science, you know, I think you learn science really well that way and it is something that is exiting to the students. I guess, I am an active learner so I found those kind of task been much more stimulating then in fact just strict sitting and listening to someone tell me about those things…… They were creative, they were clearly (pause) very interested in the subject matter themselves, so you can tell just by the way

they spoke about the subject that it is exciting to them or interesting to them. They all, the very, the best people I think knew their subject very well, so they don't know the fact all the necessary, you know I mean, I think as long as the teacher knew that there is an extra help to learn what you are trying to learn they don't have to be true experts in their subject. Sometimes the fact that they may not be an expert is actually something of an asset for students I think, you know, because questions come up and you explore the questions together and that makes it really interesting. So, I think, definitely having an enthusiasm for teaching is important too, you know, clear demonstration that the teacher cared about the student to grow and develop, you know, ability to think. And that teacher student relationship is obviously a value to teaching." (Tom)

"P – I think the best ones were those who provided me with demonstrations. I still remember my high school chemistry teacher taking a gold fish and putting it in liquid nitrogen and dropping it on the floor. Never seen liquid nitrogen before, I never touched a gold fish again. So, you remember those things for long time… I think that their best qualities were to understand where were we as students, to kind of extract them from exams and dialog in class where we were or may be more particularly where we worked and also try to show some applications from others and my view point show some applications. My chemistry teacher also taught physics in high school and so again the gold fish and other things he did he always talked about afterwards, there is smoke in the classroom with things that didn't worked, but you remember those things more then the theories. So they show some good things, knowing him who he was as a person I try to copy him myself and also the applications of the subject matter, chemistry and physics we are talking." (Ron)

Four participants expressed having no any particular good science teachers and having any particular examples of teacher qualities.

Reading interests

Most of the participants, other then reading journal articles and books on their field, read science magazines aimed for general audiences, such as "Nature", "Science", and "Scientific American", which shows that they are interested with general social issues in science. Here are some examples from the interviews:

> "I – What kind of science books do you read?
>
> P – What kind of science books do I read? Ah, well some stuff that is in the science textbooks. I like reading science that is written for more popular audiences also. So, you know, books about nature or something that are written for more broad audience that have science sort of blend to them. Ah, and I like, I also enjoy reading about subjects that I am not expert in. So I like, you know things like (laughingly) the, the more sort of (pause), well the articles in say like "Science" and "Nature" they are written for more broad audience to understand the major developments today in physics or astronomy or something that I don't really, you know, I couldn't really read the research papers, but I like to get a sense of what is happening, you know, what is new in the world of science. I read a lot of science news on the Internet. I think the Internet has been great way to spread information. There is, you know, pretty good science journalism in the Internet, I think. Ah so, on a sort of daily or weekly basis I read things like the news and views parts of the "Nature" or "Science" and the "Science Times" in the "New York Times" and then when I have

time, when I am not so busy teaching I try to read more sort of popular non-fiction stuff about nature or science." (Tom)

"P – What kind of science books do I read? Ah (pause) ok I very seldom read a science book through from start to finish, I am sure one does this when he is learning the field. Now it is a matter of ah reference library and reading papers and most of the papers I read are in "Science" and "Nature". So anyway "Science" and "Nature" and few very general journals, right now I am not, if I were involved in you know digging an animal, a research project that took all of my time as I had in the past you know I would focus on a literature in small field and look down in reasonably fewer books. Well so anyway, in science, the research anyway reading of related research papers and books that will give you an overview of the whole area, but that is not true with the humanities and the history and art the basic way of communications used to be a book." (Josh)

"P – Ah, occasionally I read books that are targeted to more general audiences. These are either things in the content area where now I teach like biology or things like the books on other aspects of biology. Ah (pause) beyond that mostly the science reading that I do is in form of journal articles occasionally, but more of news articles, perspective articles in science and things like that. It is the most science reading that I do." (Liam)

Five participants also reported reading history of science, such as biographies, autobiographies, and memoirs, which help to improve their understanding of NOS:

"P – Oh, biographies and history of science is sort of light reading. I have a preference for books which deal with works various sci-

entists did as opposed to personal life, but that is not necessarily uninteresting I read all of them. And beyond that ah (pause) I think that in the last triple decades that is probably the most of my non professional reading. And my professional reading has been mainly you know books that I used to teach my courses and so the textbooks would be upper undergraduate level or undergraduate level. Ah other leisure readings oh I would name recent books on DNA and books like that." (Don)

"P – Ah I like history of science books that you know the foundations of science where we get to where we are now in terms of whatever it is chemistry, physics, biology, it is always striking to see what it was like may be even in the turn of twentieth century, not that long ago what it was like to, to have to be a scientists and to have to be at a time where so little is known that whatever you do becomes a fundamental contribution and at the same time you have so many fewer tools. It is really interesting to see how progress is made in different conditions. History of science is something I like, but in the last few years I haven't done any particular reading of that. Between the new job and the new child, I am really out of time of starting doing anything, but in the days when I was actually reading for pleasure it was mostly things that where based in the history of science." (Peter)

"P – What kind of science books do I read? Well, I am reading my new textbook now, which I usually don't do ahead of time, but I am getting better. I got new textbooks and I am modifying the course. Let's see I have got book right here. I like to read some of the old science books as this one. It is an old, the story of variable stars. I think it was written 1941. So one of the kind of the early books on variable stars. I like to read some of the older books, I like to use them in

class, because they bring some interesting perspective. But more currently I read, I just read a book called "It must be beautiful" about equations and physics, mathematics and physics and series of short stories about E = mc2 and stuff like that. And I am reading some history of science, what was the last one; I read a great one about Tycho Brahe and Kepler, what was it called, a little history through that Copernican revolution, it was really interesting. I read the story of longitude, the great triangulation of India. So, I like to read some of the historic works." (Frank)

Few reported not having time to read outside their field.

"I – What kind of science books do you read?

P – Well, just a subject book, they are over there (pointing to shelves in his room).

I – Do you read magazines too in your area?

P – No, I have a little time. I read journals they are available online.

I – How about for the enjoyment do you read different kinds of books?

P – I used to, but now I don't have much time." (Chris)

"I – Do you read novels and fiction?

P – Absolutely! The science books that I have read for enjoyment have been sort of biographies or autobiographies and memoirs and things like that. I seldom have time now to read recreational, I was a fruitions reader when I was in elementary and junior high school and I have very little time for recreational reading since college. I occasionally read novels, actually I read one just in last week, but before that it has probably been years since I read a novel. Newspaper articles, newspapers, ah "Times" for higher education for ex-

ample. Ah I got a small child now and very good material, I don't have merely enough time to read." (Liam)

Scientific controversies followed

Nine of the participants said that they followed the teaching of evolution versus creationism and intelligent design in public school controversy, global warming controversy, and whether to do stem cell research:

"I – What kinds of scientific controversies have you followed recently or in past?

P – Ah, big one for me just sort of as an interest is ah debates about whether you can teach evolution in the classrooms and what creation science is if it is really science. And to me that is a big one and I do kind of keep an eye on that, I have clippings about that stuff right now. Ah and that is something that bothers me, worries me a little bit. So in all the classes I teach, I do a section on creation science and whether it is in fact science or not and how to recognize scientific arguments and how to recognize whether they are not scientific. So that kind of stuff I do try and get across the students and sometimes I keep track of." (Lena)

"P – I guess (pause) I am certainly very concerned about the controversies over teaching evolution in school and the whole creationism, intelligent design (pause), I try to come up with a polite word here, problem. In addition, I am certainly very concerned about the political (pause) persuasions that there is any controversy about science of climate change or most of as environmental issues where it seems pretty obvious to me that we have a problem and we should be doing something about it. As far as purely scientific controversies or

concern I haven't really been following very many of those types of things, more the political things." (Donna)

"P– Scientific controversies. Ah let's see, I follow the space exploration pretty closely. It is not so much a controversy, but there is a lot going on with the exploration of the Saturn right now, the Cassini mission. In a couple of weeks, we are going to impact an object into a comet, the deep impact mission. I have been following the Mars stuff very closely for a quite a long time. I teach lessons on Mars. And I keep a finger or hand in what is going on in astronomy, pretty much I try to in all scales, not as good at cosmology as I think I should be, but I like keep a hand on what is going on in the galactic stuff on the solar system. I am also interested in kind of geology type literature. I got pretty good background in that so I am interested in the tsunami, the kind of mechanics that occur with that global thing, global warming I follow that, ocean current changes I follow that stuff, climate change. I don't follow a lot of biology stuff, although you keep your ear in the ground about the nonsense about creationism and intelligent design. So you know I am still just, I am appalled that there are still states in the union that you know require some of these old ideas that are not scientific to be put in the science books. But, I don't follow biology too much and I don't really follow chemistry. But, I try to keep my ears to the ground on astronomy, and geophysical sciences." (Frank)

However, being interested in evolution vs. creationism controversy does not necessarily mean they discuss some aspects of it in their instruction as a way of enhancing their students understanding of NOS.

When I understood how science works

Ten of the scientists said that they understood how science really works in graduate or after graduate school. Here are some excerpts from the interviews:

"I- How did your educational experience prepared you to understand science?

P – I am not sure the extend to which my educational experience prepared me to understand science. My father is a PhD physicist and so there was always this experience as I was growing up of trying to figure out why the things were the way they were, rather then just saying that is the way it is. So that was certainly an important factor in the attraction to science. I am not sure that I really grasped how science worked until I started doing research and teaching as a graduate student before it was (pause) a little bit less connected I think" (Donna)

"I- How did your educational experience prepared you to understand science?

P – (long pause) I am not sure it did. Ah I am not sure it did at all. I mean it presented you know facts, but you are interested, if it broadens ones horizon in terms of facts and knowledge. But I think understanding of science in really deeper sense probably came much, much later, may be after I graduated from college and may be even after the PhD. I think the early it was just curiosity for whatever reason or even for myself for reasons that I don't understand." (Don)

"I- So, at what level can you say that I understand how science works, in graduate school or undergrad?

P – Ah I think ah yes by the end of the graduate school, though I understood some of it through the research experience I run on the middle of college. I was fortunate to get those research experiences early even between high school and college of age 18, very lucky until that I had no idea what science is really about." (Rich)

"I- How did your educational experience prepared you to understand science?

P – Ah (pause), well I mean, I think I had pretty good high school and middle school science program, even though it was a public school. At least in a part of upstate New York where I grew up, the school was pretty good and I had pretty good science teachers and so I feel like at that level we were doing in science things that were very sophisticated, we had a lot of experimental labs, and worked very hard at scientific writing and stuff in high school. And then in the college, here at Cornell, you know, it was a pretty good background in biology as an undergraduate. Cornell is one of the best universities in the country and especially in life sciences it is a strong school, and you know, challenging on lots of levels, but I think even most importantly beyond just learning a lot of biology information, I guess the fact that Cornell's challenging intellectual environment prepared me well to work in science and really develop.

I- At what level you can say that I understand how science works, in undergrad, or grad, or high school?

P – Ah, at what level did I…, did I think that first?

I – Understand, yeah?

P – Ah (long pause), I think I thought I understood it at each level, but I would say, I really appreciated it finally in graduate school, when I had more experience doing research and being around people that were, you know, on the cutting edge of their subfield. And

you know, I guess what I mean is that as an undergraduate and in high school we had more of the sense that science is esthetic that there are folks who you can look up for explanation and that really think about how that explanation got there or what the influences on the explanation might be, usually sort of accepted as a fact. And then in graduate school I think I hand much greater appreciation for some of the behind the scenes instances involved in science and how quickly science can change and you know, some of the things that given the fact that the information has come out from an experiment, could be bias by the person doing it. You know, people with certain backgrounds will ask certain types of questions, which will create certain types of answers." (Tom)

Three of the scientists said that they are still working on their understanding of how science works and may be they will never understand how science works:

"I- How did your educational experience prepared you to understand science?

P – How did my educational experience ah (pause) to understand science. Ah well in ways it was different. I always had some troubles learning in classroom environment and so a lot of my education I picked up on my own. I have written my first paper on fossils before I ever took an undergraduate course. I have taken graduate course too, but ah so I sort of picked up on my own. By the time I get to college I was, you know following a lot of research. A lot of high school is just plain hindrance; it is really counterproductive (laughingly). There are exceptions like science classes and even few history classes, but I don't have regret for much of that (laughingly).

I- At what level of your education you can say I understand how science works?

P – Ah it never really occurred to me to ask that. I suppose well you know if I can do it I understand it. So I just required a sense of what science was before I was seriously exposed to it in high school and (pause) it certainly creates learning by doing.

I – So would you say it was in undergraduate level or grad level?

P – What a sense of what science is I can say I am still working on it (big laughter) you know it is when you really think about it I mean it is awfully hard to define. I taught an undergraduate course for years now on Earth's evolution and one of the fundamental questions there is you know "what is science?" and "how do we find out about the Earth's history?", and "what kind of information do we look for?" and well different groups of people have wild different ideas about that, you know there is no way to explain it, you know it is the scientific process people like to engage in certain rules and go on and discuss it. What exactly are the rules we assume the everything has a range of an explanation unless you can kind of prove conclusively otherwise." (Josh)

Another three of the participants said that they understood how science works very late in college:

"I- How did your educational experience prepared you to understand science?

P – Ah (pause) to large extend, ah I suppose in high school you learn certain building blocks about how to go about science. Then in college, in college you start to see beyond just the material that you are learning and start to see science as being active and doing things

and beyond just what you read in textbooks and examinations you start to read scientific papers and you see scientific class presentations, seminars and you start to get a feel for this is actually how I should be going about doing things. It was only very late in college that really senior year in college, fourth year in college that I started to have a real idea of this is what is like to be scientists and all this stuff that I have been learning to this point while valuable, it was, I was caught up like lots of students get caught up in just what do I need to know in order to do well to pass the class. So it was only fairly late in the game that I came to realize that there was more to it then just class work and the things that students are preoccupied." (Peter)

One participant said that nothing in the educational system was designed to help him understand how science works:

"I- How you think your educational experience prepared you to understand science?

P– I don't think it helped me to understand science, I don't think anything helped me to understand science by design. In other words, I don't think that there was anything in my education that was designed to help me to understand science. I think that, that, the only thing that it was somebody taught me how to read (laughingly) they taught me how to read and they pointed me in the right direction as far as numbers and things like that, everything else I decided or figured out on my own, everything else, with no exceptions.

I – Even in the grad school?

P – By then it was, you were building on top of everything. It was too late, it was too late, when people get to be somewhere around seventh or eighth grade that is where you can tell, they are going to be a scientific type of person, an objective type of person, ah bottom line

type of person. There are lots of clichés for it, but you know some people show me the money. They want to know the number, how much is this costs, how much is this, but this, but that, how I will get that is an objective person, they give, they don't care about any bull-shit explanations or sales or anything, all they care about is I got this many apples for that many dollars and that is the bottom line, that is a scientific type of person." (Jack)

These findings reveal that American K-16 science education system is not helping students understand the workings of science, even among the best ones, the ones that are self interested and motivated to pursue career in one of the sciences.

Discussion and conclusion

Data reveal that participants generally had a public schooling experience and had varying experiences in research and teaching in college. Their interest in science generally started as self-motivated and self-interest in middle and high school years, except for the three female scientists who got interested in science in their college years. Their parents were generally college graduates and supported them in their education in general, but did not give them any particular guidance in getting into their field of science. Most of the participants described their best science teachers as being, enthusiastic and exciting about their subject, motivating and involved with their students, and as a person who uses a lot of demonstrations and hands-on experiments. The participants were interested with general social issues in science, such as evolution vs. creationism and stem cell controversy. The majority of the scientists said that they understood how science really works in graduate or after graduate school.

These findings show that students' self interest and motivation in science might be very crucial in shaping their future and choosing science as a

career path. Moreover, some informants noted a strong parental influence in their lives that influenced their pursuit of a science career, which supports the findings of Monhardt et al. (1999). Parents' educational and social backgrounds, as suggested by Shavelson & Towne (2002), also could be of some importance in shaping their educational interests and starting talk about science inside family. Students from middle-class families and particularly students who have college graduate parents could have more talk about science and its workings in the family than working-class and poor students, because of their parents' cultural capital. Thus, it can create inequality in the schooling experience among students within different class backgrounds. So teachers' use of language in the classrooms and their enthusiasm about the subject becomes more crucial in mitigating this inequality and supports the findings of Karakas (2013). Furthermore, the fact that most of the participants said that they understood how science really works in graduate or after graduate school supports the findings of Kardash (2000) and Hunter et. al. (2006) and shows that American K-16 education system is not structured to help students understand the way science works even among the best ones, the ones that are self interested and motivated to pursue career in one of the sciences, or maybe it might be a completely developmental issue and that it is unlikely that K-16 students have enough sophistication or knowledge base to be able to appreciate the nature of science. This late understanding of the workings of science may be due to the fact pointed out by Kuhn (1970) who writes:

> [I]n these fields (contemporary natural sciences) a student relies mainly on textbooks until, in his third or fourth year of graduate work, he begins his own research. Many science curricula do not ask even graduate students to read in works not written specifically for students. The few that do assign supplementary reading in research papers and monographs restrict such assignments to the most advanced courses and to materials that take up more or less where the available texts

> leave off. Until the very last stages in the education of a scientist, textbooks are systematically substituted for the creative scientific literature that made them possible (p.165).

This should be of big concern for science educators and for society in general if we want to have educated citizens who can decide for themselves what is good and what is bad for their wellbeing in a democratic society.

APPENDIX

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?

REFERENCES

AAAS [American Association for the Advancement of Science]. (1989). *Project 2061: science for all Americans*. Washington: Author.

Abd-El-Khalick, F. & Lederman, N.G. (2000). Improving science teachers' conceptions of nature of science: a critical review of the literature. *Int. J. Sci. Educ., 22,* 665-701.

Bell, D. (1993). Yes Virginia, there is a feminist ethnography: reflections from three Australian fields (pp. 28-43). In: Bell, D., Caplan, P. & Karim, W.J. (Eds.). *Gendered fields: women, men, and ethnography.* Abingdon: Routledge.

Bogdan, R. & Biklen, S.K. (1998). *Qualitative research for education: an introduction to theory and methods.* Boston: Allyn & Bacon.

Creswell, J.W. (2011). *Educational research: planning, conducting, and evaluating quantitative and qualitative research.* Upper Saddle River: Merrill Prentice Hall.

Durkee, P. & Cossman, G. (1976). Views on the nature of science among college science faculty. *49th Annual Meeting of the National Association for Research in Science Teaching*, San Francisco, USA.

Duschl, R.A. (1985). Science education and philosophy of science twenty-five years of mutually exclusive development. *School Sci. & Math., 85*, 541-555.

Glasson, G.E. & Bentley, M.L. (2000). Epistemological undercurrents in scientists' reporting of research to teachers. *Sci. Educ., 84,* 469-485.

Hunter, A., Laursen, S.L. & Seymour, E. (2006). Becoming a scientist: the role of undergraduate research in students' cognitive, personal, and professional development. *Sci. Educ., 91,* 36-74.

Hurd, P.D. (1960). *Biological education in American secondary schools, 1890-1960.* Washington: AIBS.

Irez, S. (2006). Are we prepared: an assessment of preservice science teacher educators' beliefs about nature of science. *Sci. Educ., 90,* 1113-1143.

Karakas, M. (2006). *College science professors' understanding and use of nature of science: PhD thesis.* Syracuse: Syracuse University.

Karakas, M. (2008). *Science professors' understanding and use of nature of science*. Saarbrücken: VDM.

Karakas, M. (2013). Prospective elementary teachers' views on their teachers and their effectiveness. *Qualitative Report, 18,* 1-17.

Karakas, M. (2018). Problems in teaching introductory science classes: views of few scientists. *Eur. J. Educ. Studies, 5*(6), 41-58.

Kardash, C.M. (2000). Evaluation of an undergraduate research experience: perceptions of undergraduate interns and their faculty mentors. *J. Educ. Psychology, 92,* 191-201.

Kimball, M.E. (1967). Understanding the nature of science: a comparison of scientists and science teachers. *J. Res. Sci. Teaching, 5,* 110-120.

Kuhn, T. (1970). *The structure of scientific revolutions.* Chicago: University of Chicago Press.

Lederman, N.G. (1992). Students' and teachers' conceptions of the nature of science: a review of the research. *J. Res. Sci. Teaching, 29,* 331-359.

Magolda, M.B.B. (2004). Evolution of constructivist conceptualization of epistemological reflection. *Educ. Psychologist, 39*(1), 31-42.

Monhardt, R.M., Tillotson, J.W. & Veronesi, P.D. (1999). Same destination, different journeys: a comparison of male and female views on becoming and being a scientist. *Int. J. Sci. Educ., 21,* 533-551.

NRS [National Research Council]. (1996). *National science educational standards.* Washington: National Academy Press.

NSF [National Science Foundation]. (1996). *Shaping the future: new expectations for undergraduate education in science, mathematics, engineering, and technology: a report on its review of undergraduate education by the Advisory Committee to the Directorate for Education and Human Resources, NSF Publication No. 96-139. Arlington*: Author.

NSSE [National Society for the Study of Education]. (1960). *Rethinking science education (59th Yearbook, Part I).* Chicago: University of Chicago Press.

NSTA [National Science Teachers Association]. (1982). *Science-technology-society: science education of the 1980's.* Washington: Author.

Pomeroy, D. (1993). Implications of teachers' beliefs about the nature of science: comparison of the beliefs of scientists, secondary science teachers, and elementary teachers. *Sci. Educ., 77*, 261-278.

Roth, W.-M. & Lucas, K.B. (1997). From "truth" to "invented reality": a discourse analysis of high school physics students' talk about scientific knowledge. *J. Res. Sci. Teaching, 34*, 145-179.

Saunders, H.N. (1955). *The teaching of general science in tropical secondary schools.* London: Oxford University Press.

Schwartz, R.S. (2004). *Epistemological views in authentic science practices: across-discipline comparison of scientists' views of nature of science and scientific inquiry: PhD thesis.* Corvallis: Oregon State University.

Shavelson, R.J. & Towne, L. (2002). *Scientific research in education.* Washington: National Academy Press.

Van Maanen, J. (1988). *Tales of the field: on writing ethnography.* Chicago: University of Chicago Press.

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