THE BROADER IMPACT OF STUDENT-SCIENTIST PARTNERSHIP: SCIENTISTS’ CONTRIBUTION TO STUDENTS’ UNDERSTANDING AND PROFICIENCIES OF SCIENCE

A Dissertation

by

GOKHAN OZTURK

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Chair of Committee,	Carol L. Stuessy
Co-Chair of Committee,	Bugrahan Yalvac
Committee Members,	Cathleen Loving
	Lawrence Griffing
Head of Department,	Yeping Li

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ABSTRACT

This study aims to investigate the broader impacts of student-scientist partnership with an emphasis on scientists' possible contributions to students' understanding and proficiencies of science. Appeals from the National Science Foundation have specifically called for broader participation and direct involvement in science and the enhancement of research and education through the linking of scientists with other programs. The Botanical Society of America's *PlantingScience* project is a partnership of students, science teachers, and scientist-mentors working together in authentic science learning. This dissertation includes three papers. The first paper is an extensive literature review focusing on how scientists can contribute to students' science learning via online mentoring. The second paper applies a grounded theory approach to build a theory that explains how scientists talk about science when they engage in inquiry activities with students and how this interaction occurs. The third study, which is a mixed methods study, investigates how scientists contribute to students' science proficiencies and what kind of patterns exist between scientist-mentors and student-teams during inquiry engagement.

The literature review reveals an information gap exploring how scientists reflect their understanding of science to K-12 students when they work together in a partnership model. This review pointed out three main questions regarding student-scientist partnerships via online mentoring: (1) What do scientists say about science when they engage in online dialogue about students' inquiry projects? (2) What are the connections

between scientists' demographics, the subject of the inquiry, and the way they explain the nature of science? and (3) What is the relationship between the quality of students' inquiries and what their mentors reveal about the nature of science in their dialogues? The results of the grounded theory study revealed the educational, social, and cultural means of the interaction between two parties-- students and scientists. Also, investigation of various cases allowed a better understanding of the essence of nature and culture of science from practitioners' perspectives. Finally, the mixed methods study revealed that scientists contributed to the authenticity of students' inquiry experiences by encouraging them to understand scientific explanations, generate scientific evidence with them, reflect on scientific knowledge, and participate productively in scientific discussions.

DEDICATION

I would like to dedicate this dissertation to my father, Metin Ozturk, I lost very early.

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NOMENCLATURE

ICT	Information and Communication Technologies
NGO	Non Governmental Organizations
NOS	Nature of Science
NRC	National Research Council
NSES	National Science Education
SSP	Student Scientist Partnership
STEM	Science Technology Engineering Mathematics

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CHAPTER I

INTRODUCTION

We live in an era in which science has diffused every component of life and is inseparable from our physical environment. In this sense, in both our daily and professional life having knowledge of science and skills at a level that can make us capable of carrying out daily tasks is more than a necessity; it is an inevitable truth. In addition, in a competitive world where having a job and making global or nationwide business highly depend on manufacturing technology products and use of that technology in business in an effective way. In 2007, Committee on Science, Engineering, and Public Policy released a report entitled *Rising above the Gathering Storm: Energizing and Empowering America for a Brighter Economic Futur*e. According to this report science is critical for public in our century to (a) ensure economic well-being, (b) creating new industries, (c) promote public health, (d) care for environment, and (e) improve standard of living (Committee on Science, Engineering, and Public Policy, 2007). However, the same report also stated that US primary and secondary education is not able to possess skills, knowledge, and motivation regarding science that they can compete with other countries in the emerging world. Recent studies in education literature also indicated similar findings. For example, results of the *National Assessment of Education Progress* (Grigg, Laucko & Broagway, 2006) revealed that 32% of the grade 4 and 41% of grade 8 students scored below the “basic” level and only 25% of grade 4 and 19% of grade 8 scored at or above “proficient” level in science. Other research showed that although teachers engage students in all strands of science proficiencies, they have limited science related background and do not feel confident about authentic science (Minogue, Madden, Bedward, Wiebe, & Carter, 2010). Moreover, in general, science teachers' ability to teach nature of science is not adequate because according to research they do not possess required science understanding that students can benefit from (Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000). Thus, while science teachers can be well prepared to teach about science, it seems that they do not have required skills and knowledge to teach what science is.

In addition to the teacher-related problems mentioned above, there are some persistent fundamental problems that affect both theory and practice of science teaching. For instance, although scientific inquiry has been suggested as the main approach to teach science at schools in formal school settings (National Research Council, 1996), the majority of science as it is taught in schools does not represent the practices of authentic science (Falloon & Trawern, 2012) and the practices that students experience are not aligned with the science content (Schwartz, Weizman, Forts, Krajck, & Reiser, 2008). Most importantly, none of the problems listed here can be ignored or over estimated because for most of the students their experience with science in school may be the only science experience that they will have in their life (Moss, 2001).

Teaching through inquiry attempts to integrate authentic science activities into science classrooms. However, inquiry can be challenging for teachers who lack confidence in presenting science processes and science understanding to their students.

The broader participation and direct involvement of scientists in promoting science within the public sphere could be an alternative approach to empower science teaching in K-12 education. Inquiry oriented learning approaches augmented with scientists' mentoring can help students be informed about how science works and what scientists do. Scientists and students' collaboration can be an ideal venue for the students to engage in authentic scientific inquiry. In K-12 levels, however, students learning science have very limited interaction with scientists.

The National Research Council (NRC) (2010) recommends scientists' involvement in science education to help students experience science in the way experts practice science. According to the literature, student-scientist partnerships increase students' content knowledge and attitude towards science (Houseal, 2010; Baumgartner, Duncan, & Handler, 2006), and change students' perceptions about science (Marx, Honneycut, Clayton, & Moreno, 2006). Also, scientist-mentored students perform better in authentic science activities (Hay & Barab, 2001), and develop sophisticated science understanding (Aydeniz, Baksa, & Skinner, 2011). Another important benefit that student scientist partnerships provide is that it allows students to participate in scientific discourse, which is central to science learning and science education (Newton, Driver, & Osborne, 1999). Students engaged in a scientific discourse with scientist developed more sophisticated understanding of science (Eastwood et al., 2012).

However, there are relatively few examples of studies in science education literature that explore how scientists explain what science is and how scientific knowledge is being developed. The existing data only relies on surveys and scientist interviews, which should not be accepted as the only data source (Abd-El-Khalick, 2011). In this sense, case studies are needed because they allow us to learn from scientists' unique expressions about science that exemplifies contemporary science practices and science progress (Schwartz, 2012).

In addition, implications of a scientist- student partnership model without geographical and logistical boundaries can help science educators reach many students nationwide. Technology provides opportunities otherwise not realistic for scientists to engage in classroom learning. Online learning can provide added opportunities for students and scientists to communicate anytime and anywhere at a distance, which is otherwise impossible. Technologies such as Web 2.0 offer great opportunities for partners of partnerships to communicate (Edelson, 2001). Studies have revealed that student-scientist partnerships without a well-established interaction and communication do not accomplish attained learning objectives (Moss, 2001, 2003).

The Botanical Society of America's *PlantingScience* project provides opportunities for plant scientists to contribute to the call for broader impacts. Once introduced in the science classroom, *PlantingScience* becomes a partnership of students, science teachers, and scientist-mentors working together in authentic science learning. *PlantingScience* employs an innovative partnership model enabling students to learn about science in ways beyond a typical school classroom experience. While science teachers can be well prepared to teach about science, few actually have done science themselves and are therefore unable to offer the professional perspectives of individuals who actually engage in scientific discovery themselves. Through a blend of the regular classroom setting and an online portal, *PlantingScience* provides opportunities for scientists, teachers, and students to collaboratively engage in authentic science in ways benefitting all parties. Scientist-mentors provide a unique, important dimension to the science classroom. They actually teach science through engagement in the scientific process, a way not usually available to the classroom teacher. Through *PlantingScience,* scientists are enabled to do what they do best: contribute their own knowledge and experiences to novice learners from their perspectives as experts who "do science" in their professional lives. Through the online component of the project, scientists are able to make broader impacts on students' science learning. Consequently, the teacher’s job of teaching science in an authentic manner is supported and supplemented.

The dissertation, as a whole, aims to investigate the broader impacts of student-scientist partnership with an emphasis on scientists’ possible contributions to students’ understanding and proficiencies of science. This dissertation consists of three studies, sharing a common introduction and a conclusion. The first study (Chapter II) is an extensive literature review focusing on how scientists can contribute to students’ science learning via online mentoring. The second study (Chapter III) applies a grounded theory approach to build a theory that explains how scientists talk about science when they engage in inquiry activities with students and how this interaction occurs. The third and the final paper (Chapter IV) is a mixed methods study investigating how scientists contribute to students’ science proficiencies and what kind of pattern exists between scientist-mentor and student-team inquiry engagement. The final chapter (Chapter V) is a conclusion section in which I discussed outcomes of the three study, their contributions to literature, and suggestions for further studies needed to investigate scientists' contributions to students' understanding and proficiencies of science.

The purpose of the literature review study was to draw attention to the role of student-scientist interaction in learning about science by addressing theoretical and practical aspects of science and science education. The first section begins with a discussion of the contemporary view of science in regard to the philosophical foundations of science. These consist of (1) the historical and philosophical background regarding our view of science, (2) the nature of science (NOS) and scientific inquiry, (3) views of science, and (4) scientists' view of NOS sections. The second section is a discussion of the practical, educational foundations of the study, particularly as they relate to students' needs to understand the contemporary view of science. The practical foundations of the study focus on (1) partnerships of students and scientists, (2) the role of technology in facilitating such partnerships, and (3) an exemplary program, *PlantingScience*, as a model bringing together philosophical and practical foundations of science and science education, respectively. In the final section, I pull all of my thoughts together in a conclusion that draws attention to the role of student-scientist interaction in learning about science, the scientist's role in students' understanding of science, and the rationale discussing the need for the proposed research.

The second study aims to investigate how scientists and students engage in scientific inquiry and in which ways they interact with each other in an authentic science experience through online communication. Revealing the educational, social, and cultural means of interaction in this student-scientist partnership can help us, as educators, to better understand the essence of nature and culture of science from practitioners' perspective. I chose a qualitative approach to better understand the dialogues between students and scientists. The units of analysis for this study are naturally occurring dialogues between student groups, usually four in number, and including their assigned scientist. The sample for the analysis was selected from 36 inquiry groups, which included more than 140 students and 36 scientists. I employed a grounded theory research approach and analyzed the data obtained from the student-scientist dialogues using constant comparative method (Glaser & Strauss, 1998).

The third study investigated how and what scientist can contribute to students' science proficiencies. We used a rubric derived from a science proficiencies analytic framework for interpreting the communication of scientists to "learn more" about the contribution of scientists in the *PlantingScience* learning environment. In this study, mixed methods employed an embedded multiple-case replication design and descriptive statistics that allowed interpretattion of collected data (Schreiber, 2008). According to Yin (2014), embedded multiple group case study designs provide more robust results compared to single case study design by replicating and confirming findings from studied group. The units of analysis (i.e., cases) for this study were 10 student-teams who participated in planting science in the fall of 2011. One science teacher taught these students in two separate classes. Each student-team was partnered with a scientist-mentor volunteer who was assigned by the Botanical Society of America. Analysis of the naturally occurring dialogues between two parties revealed the structure of talk that can reveal if scientists can really provide benefit to students' science learning and how they manage it from the science proficiencies framework perspective.

Research Questions

Study 1

The first study is an extensive review of the literature focusing on how scientists contribute to students' science learning via online mentoring. The research questions leading this review are:

1) What are scientists' contributions to science learning via online mentoring?

2) What do the existing literature suggest for further studies related to this topic?

Study 2

A review of the literature revealed an information gap exploring how scientists reflect their understanding regarding the NOS. Previous studies propose research intending to investigate student-scientist mentorships by analyzing scientist-student dialogues. The aim of this particular study is to answer these questions:

1) How do scientists talk to students about the nature and features of science, specifically botanical science?

2) What do scientists say about science when they engage in online dialogue about students' inquiry projects?

3) What are the connections between scientists' demographics, the subject of the inquiry, and the way they explain the nature of science?

Study 3

The purpose of this third study is to investigate how scientists can contribute to students' scientific inquiry experiences in science classes. An analysis of the naturally occurring dialogues between two parties can reveal the structure of talk between scientists and student-teams. Results of the analysis can support claims that scientists do really provide benefits to students' science learning. Use of a science proficiencies framework can provide insights regarding the types of benefits provided. For this investigation, the two questions are:

1) How do scientists contribute to students' scientific inquiry experiences?

2) What are the cognitive contributions of scientists to students' authentic inquiry experiences with respect to the four strands of science proficiencies?

CHAPTER II

SCIENTISTS' CONTRIBUTIONS TO SCIENCE TEACHING VIA ONLINE MENTORING: A REVIEW OF THE LITERATURE

Introduction

Imagine that you hear the bell ringing in a contemporary U.S. high school signaling the end of one class session and the beginning of another. In this scenario, you also observe students in an introductory biology class tumble into their science classroom and immediately go to check out any changes in the two sets of plants they have growing under lights at their learning stations. Stations are equipped with a computer and time-lapse cameras focused on each set of plants, which make 24-hour records of plant responses to the environment. Upon arrival at their stations, students download, store, and view videotapes of their plants' responses on the computer at the learning station. They take careful notes of their observations and then proceed to observe the two groups of plants growing under the lights. They observe and measure their plants, indicating morphological differences between plants within and between the two sets All records are kept in their lab notebooks, which are stored at the learning station and used to compare new observations with those made previously.

Over time, students' records reveal some remarkable differences between the two sets of plants. Students know that one group of plants growing at their station has a gene that has been chemically altered to affect the plants' responses to factors present in the plant's environment. Students do not know, however, what the gene specifically controls; they only know it is a gene controlling some aspect of plant growth and/or response. Students also know that the genes in the plants of the other group are "normal." Comparisons of plant growth and responses of the plants in the two different groups can reveal what types of plant responses are controlled by the chemically treated gene. In the genetically altered plants at this student group's station, for example, the leaves are observed to close in the daytime and open at night, while the leaves in the typical plants respond in the opposite way. While student groups do not know the normal function of the altered gene before their experiments begin, their careful observations and comparisons with typical plants can provide evidence of the purpose of the gene. The purpose of all students' investigations in this class is to collect data to support a conclusion about the function of the altered gene in the plants they are observing. Day-to-day records of changes in plant responses to the environment are therefore very important to support the conclusions the students will eventually make.

Throughout the inquiry, the students also post their observations on an online communications portal, which provides opportunities for the students, the teacher, and the plant scientists to read and make comments about students' experiments. Furthermore, the portal also allows opportunities for the scientists to mentor their assigned student teams while they are performing their investigations. Students within the special online community share their findings, make daily update to their data, and receive feedback about their experiments. The inclusion of scientist mentors in the processes of students' "doing science," therefore, create advantages for students in learning science. Interactions with scientists enhance the development of students' reasoning skills, incite students' interest in science, and forge the students' familiarity with authentic science—a very difficult thing for science students to experience within typical science classroom learning environments. Even though the students do not work in a laboratory with real scientists, engaging in scientific discourse with a real scientist allows the students to glimpse the world of science.

The aforementioned narrative can be perceived as unrealistic, futuristic scenario because our current education system is primarily based on traditional teaching methods. However, the project entitled *PlantingScience* has already initiated such interactions, and after five years of research, development, and implementation, the above scenario has become a realistic, tangible means of submersing students into the field of science. The *PlantingScience* project has allowed thousands of students to interact and work with scientist mentors through online mentoring while also administering hands-on activities in their science classrooms. Under the light of the *PlantingScience* model, it is obvious that the adoption of a contemporary view of science education can offer a variety of opportunities for students to learn science and experience scientific practice in formal school settings.

The purpose of this literature review is to draw attention to the role of student-scientist interaction in learning about science by addressing two main aspects of science and science education: (1) What is the contemporary view of science? and (2) What is the contemporary view of science education? This literature review contains three sections. The first section focuses on the contemporary view of science; the second focuses on the contemporary view of science education; and the third focuses on combining these two contemporary views in the study of a particular innovative science-learning environment.

The first section begins with a discussion of the contemporary view of science in regard to the philosophical foundations of science. These consist of (1) the historical and philosophical background regarding our view of science, (2) the nature of science and scientific inquiry, (3) views of science, and (4) scientists' view of Nature of Science (NOS) sections.

The second section allows a discussion of the contemporary view of science education; I discuss the practical, educational foundations of the study, particularly as they relate to students' needs to understand the contemporary view of science. The practical foundations of the study focus on (1) partnerships of students and scientists, (2) the role of technology in facilitating such partnerships, and (3) an exemplary program, *PlantingScience*, as a model bringing together philosophical and practical foundations of science and science education, respectively.

In the final section, I put all of my thoughts together in a conclusion that draws attention to the role of student-scientist interaction in learning about science, the scientist's role in students' understanding of science, and the rationale discussing the need for the proposed research. The approach that I used in my literature review was to support a theoretical concept based on contemporary views of science and science education. The review of literature as a whole can provides the basis for further research explaining how scientists reflect their understanding of science through a student-scientist partnership.

What Is the Contemporary View of Science?

Historical and Philosophical Background

What is the motivating question behind science? What is science? How do we teach science? These are some of the questions that have been answered by scholars in different fields. As always, there are multiple perspectives about the components of science and how it should be taught. From antiquity to the first years of the 17th century, science was taught linked to philosophy (Zhmud, 2006). Over time, science philosophers proposed varied explanations about science and scientific practice. For example, Karl Popper discussed the falsification of scientific theories and experimental science in the 20th century. Popper (1963) proposed "a theory which is not refutable by any conceivable event is non-scientific. Irrefutability is not a virtue of a theory (as people often think) but a vice" (p. 35). Popper also explained the process of science as the accumulation of new knowledge, which is built on existing theories (Thornton, 2013).

After Popper's attempt discussing the philosophy of experimental or modern science, another philosopher, Thomas Kuhn (1996), also a physicist, stated that unlike a linear and continuous development, science progresses through revolutionary paradigm shifts. These shifts occur as a need in society, not necessarily on the needs of science itself. As Kuhn rejected the idea of explaining science as the accumulation of knowledge and as a unidirectional process, he was subjected to a lot of criticism from his contemporaries. Imre Lakatos proposed a research program idea that covers both Kuhn' and Popper's ideas. He explained that the development of science was not discrete; instead, it progressed through some major changes and addition of new knowledge to the existing ones (Lakatos, 1970). Even though the discussion among these philosophers forms the backbone of the philosophy of science in the last century, Lakatos, Kuhn, and Popper's ideas are still open to discussion and are subject to modifications.

For pedagogical purposes, the philosophy of science discussions over the last century have become a keystone in science education and science teaching. In conjunction with the changes in the philosophy of science, science teaching in formal educational settings has also changed. It moved from a knowledge-centered, pure science understanding to include human-centered understandings of science—this includes *science literacy* that aims to make people aware of science and be able to apply scientific knowledge in making decisions, solving problems, and successfully working in a rapidly advancing, highly technological world. Recently, the philosophy of science discussions have evolved to include *scientific inquiry* as a human activity for all learners. Scientific inquiry requires students to evolve from being passive learners to active practitioners of science. The detailed information about science literacy and scientific inquiry will be mentioned in further sections of the review.

NOS and Scientific Inquiry

Scientific inquiry is a process where the characteristics of science are practiced and scientific knowledge is generated (Lederman, 2004; Schwartz, Lederman, & Crawford, 2004). Inquiry and authentic inquiry are the two terms often used to describe the process of investigation used in laboratory settings (Chinn & Malhotra, 2002; Driver, Leach, Millar, & Scott, 1996; Schwartz et al., 2004). When we use the term "scientific inquiry" in an educational context, the term refers more to a pedagogical method –

inquiry teaching– that mirrors the authentic inquiry by highlighting students' questioning, problem solving, and investigation (Deboer, 2004).

The first notions of inquiry teaching date back to the beginning of the 20th century. In his essay, *Experience and Education*, John Dewey (1938) suggested that science education should be taught through everyday applications, including the acquisition of scientific knowledge and facts regarding the context and social interactions. His ideas about teaching science indicated an experiential learning approach, which was based on collaboration and the democratic contribution of students in learning and teaching. Until the late 1950s, initial attempts to implement scientific inquiry in educational policies did not go much further than domain specific science applications.

By the early 1970s, science education research began to focus on providing citizens with scientific skills and awareness to function effectively in a scientific world (Deboer, 2004). This movement was dubbed "*scientific literacy* or *science for all,"* intending to make science more accessible for average people. The movement also encouraged the public to be interested in science and to be involved with scientific decisions. The main connection of scientific literacy to science education and classroom implications was the inclusion of science, technology, and society topics in the science curriculum.

Today, society deems science as a practical tool; therefore, we can trace parallel changes in the conception of science with changes in the way science is taught. Misconceptions presume science is a domain-specific knowledge and information for an elite group of science-minded individuals. These misconceptions have spawned the demand for new notions about science literacy. The new notions proclaim science literacy is for all individuals by providing useful information for the betterment of all humans on Earth. The shift in perception had created a new way to teach science—instead of observers, students should be decision-makers.

In 1996, the generation of the *National Science Education Standards (NSES)* in the United States launched scientific inquiry into the forefront of people's minds. NSES detailed and organized a unique teaching approach having its own philosophy, objectives, and methods. The *NSES* (National Research Council, 1996) described inquiry as the main method for teaching science instead of proposing it as a tool. In standards, scientific inquiry was defined as follows:

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (p. 23).

As indicated, the *NSES* describes scientific inquiry in two ways. First, scientific inquiry is described as the development of skills that students use to effectively conduct scientific investigations. These skills include science process skills and abilities such as data gathering, questioning, designing, reviewing, and looking for other sources. Second, scientific inquiry is described as the development of an understanding of science, which is mentioned in the following sections of the NOS. Figure 1 provides a matrix from the

NSES companion volume, *Inquiry and the National Science Education Standards* (2000). This figure summarizes the essential features of classroom inquiry and describes the range of variation from teacher-directed to student-centered. Students should spend some time on the "student-centered" side of this diagram, but teacher guidance is needed to help students develop the needed skills and to guide them to consider ideas they might not otherwise encounter. A common misconception about inquiry learning is that all activities must be "discovery" learning—this is when students pose their own questions and explore what interests them. This diagram shows how teachers can guide some parts of the inquiry process while still allowing students to build concepts themselves.

We see in reports that the NRC and other studies published in the last two decades have addressed scientific inquiry as a method for teachers. The reports discussed scientific inquiry with a broader meaning. It also extended its definition and provided principles that guided teachers with a new teaching method: teach science through inquiry. For instance, the *How People Learn* (Bransford & Donovan, 2005) committee approached scientific inquiry as a method from teachers' perspectives to support students (1) to learn new concepts and ideas deeply, (2) to experience the process of inquiry and the culture of science, and (3) to meta-cognitively reflect on their thinking and participate in inquiry. Furthermore, the NRC (2007) developed four strands of scientific practices that reflect the link between the learning side of science teaching and inquiry in the classroom. These strands have aimed at encouraging students (1) to understand and interpret scientific explanations, (2) to generate scientific evidence, (3) to reflect on their scientific knowledge, and (4) to participate productively in science as a social enterprise having its own norms and values.

Essential Feature	Variations			
1. Learner engages in scientifically oriented questions	Learner poses a question	Learner selects among questions, poses new questions	Learner sharpens or clarifies question provided by teacher, materials, or other source	Learner engages in question provided by teacher, materials, or other source
2. Learner gives priority to **evidence** in responding to questions	Learner determines what constitutes evidence and collects it	Learner directed to collect certain data	Learner given data and asked to analyze	Learner given data and told how to analyze
3. Learner formulate **explanations** from evidence	Learner formulates explanation after summarizing evidence	Learner guided in process of formulating explanations from evidence	Learner given possible ways to use evidence to formulate explanation	Learner provided with evidence and how to use evidence to formulate explanation
4. Learner connects explanations to scientific knowledge	Learner independently examines other resources and forms the links to explanations	Learner directed toward areas and sources of scientific knowledge	Learner given possible connections	
5. Learner communicates and justifies explanations	Learner forms reasonable and logical argument to communicate explanations	Learner coached in development of communication	Learner provided broad guidelines to use sharpen communication	Learner given steps and procedures for communication

More ——— Amount of Learner Self-Direction ——— Less
Less ——— Amount of Direction from Teacher or Material ——— More

Figure 1. Essential features of classroom inquiry and their variations. Retrieved from "Inquiry and the National Science Education Standards: A Guide for Teaching and Learning" by National Research Council, 2000, p. 29.

However, scientific and authentic inquiries have some fundamental epistemological differences. According to Chinn and Malhotra (2002), inquiry activities do not reflect the authenticity of science. These authors claimed that the inquiry tasks given to students in school were cognitively and epistemologically different from the authentic science experts in the field. Chinn and Malhotra discussed the differences between school and authentic science in a study consisting of two main sections.

In the first section, authors compared the epistemology of simple inquiry activities with the epistemology of authentic science by using *models of data theory*. This theory basically assumes that individuals construct a particular cognitive model and this model combines the characteristics of the data with a theoretical interpretation (Chinn & Brewer, 2001). In this regard, researchers contrasted authentic science activities with simple inquiry tasks. It should be noted that in the study the term *simple inquiry* refers to the school science activities such as simple experiments, simple observations, and simple illustrations. The results revealed that epistemological cognitive structure and the flow of authentic and simple inquiry activities are different from each other.

In the second part of the study, Chinn and Malhotra (2002) analyzed 492 simple inquiry tasks and inquiry activities designed to be similar to authentic inquiry activities prepared by researchers. According to the results, inquiry activities in textbooks could only capture a limited part of the cognitive and epistemological aspects of authentic science.

Additionally, some concepts in authentic science are not applicable in the science education context because the results of most school science experiments are already known by the teacher or written in the textbooks (Chinn & Malhotra, 2002). In most textbooks, science, which is in fact a dynamic process, is portrayed as a linear or a stationary process (Irez, 2009). Textbooks often portray a universal and structured method of science. Therefore, today's school science requires the integration of context, process, and understanding of science. These components should be provided together in order to approach the authenticity of science in the classroom environment.

However, the problem of reflecting the essence of authentic science or real science in the classroom is bigger than the methodological issues because "science is not only a body of knowledge, but also a way of knowing. One important underpinning for learning is students' understanding of the nature and structure of scientific knowledge and process by which it is developed" (National Research Council, 2007, p.168). Although science education standards and government related reports promote scientific inquiry as the goal of the science teaching, science educators and philosophers all agree that science teachers are not well trained and lack understanding of real or authentic science (Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000). Moreover, most teachers possess naïve understandings of science and may not be able to teach due to a lack of understanding of science (Akerson & Abd-El-Khalick, 2005). In addition, a fundamental question remains whether the NOS and scientific inquiry are universal and influenced by the scientific discipline studies. The answer has not been investigated by researchers in the field (Lederman, 2007).

Before going into the details, we should make clear what we mean by using the term the NOS or one's understanding of science. One's understanding of science is the subject of the study of NOS. Abd-El-Khalick and Lederman (2000) defined the NOS as follows: "The phrase "nature of science" typically refers to the epistemology of science,

science as a way of knowing, or the values and beliefs inherent to scientific knowledge or the development of scientific knowledge" (p. 666). In other words, NOS refers to the assumption that is intrinsic to scientific knowledge including its values, limitations, and influences as a human endeavor (Schwartz et al., 2004). However, beyond the general definition, there is a considerable disagreement regarding the meaning of NOS among historians, philosophers, and science educators (Lederman, 2004).

There has been an extensive effort to conceptualize and develop an empirical basis for developing individuals' understanding of science in the last fifty years. For instance, Lederman and his colleagues (Lederman, 1992; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002; Schwartz & Lederman, 2008) have developed a framework and designed a series of instruments to understand peoples' knowledge and conceptions of science. Most of these instruments have been constructed to use open-ended, qualitative measures.

According to Lederman, seven main themes represent the understanding of the NOS. These are (1) empirical nature of scientific knowledge, (2) scientific theories and laws, (3) creative and imaginative nature of scientific knowledge, (4) theory-laden nature of scientific knowledge, (5) social and cultural embeddedness of science, (6) myths of scientific method, and (7) tentative NOS (Lederman et al., 2002). As Lederman et al. (2002) explained, the empirical nature of scientific knowledge refers to scientific knowledge based on inferences, observations, and collection of theoretical ideas. The recurring idea of scientific theories and laws illustrates how their role explains bigger phenomena in nature.

The creative and imaginative NOS theme refers to the involvement of human creativity and imagination through the generation of scientific knowledge. The theory-laden NOS theme refers to science as a theory-driven process and how it is affected by socioeconomic, political, and social changes that refer to the social and cultural embeddedness of science. The sixth theme, the myth of a single scientific method, clarifies that there is no one single method of science that is common for all science disciplines. The last theme, which is the tentative NOS, corresponds to the uncertainty and durability of scientific knowledge. Finally, the independence aspect was added as a new dimension to describe the relatedness of the seven categories with each other (Schwartz & Crawford, 2004).

From a different perspective, Sandoval (2005) explained students' NOS as the epistemology of inquiry that focuses on students' ideas about nature of scientific knowledge and methods used to generate that type of knowledge. According to this author, two types of epistemologies exist. The first one was the practical epistemology that students applied to their own scientific knowledge they build through inquiry. The second one was the formal epistemology that students hold about their own knowledge in formal science.

Sandoval also stressed science education has conceptualized NOS in different ways. He describes the purpose of science education as a transfer of students' formal epistemologies to more practical epistemologies regarding their understanding of science, which is acquired through participation in authentic inquiry activities. Methodologically, Sandoval (2005) suggested that researchers should explore the artifacts produced and the discourse students used when constructing and evaluating the artifact through inquiry.

Views of Science

The need for including the NOS continues to be a requirement in teaching about authentic science in schools. However, as mentioned before, there is a considerable disagreement on the NOS dimensions among philosophers and science educators (Alters, 1997a). While some researchers believe that teaching NOS through a list of themes as declaratives, NOS is dangerously perceived as a learning target before we learn more about it (Ford, 2008). Others conceive "science is thus being transformed from an individualistic community into a homogenous collective enterprise, which now covers all types of research from the academic to the technological" (Ziman, 1983, p. 1), and it is domain general (Urhahne, Kremer, & Mayer, 2011). In the following section, we will discuss views of science held and supported by researchers from a broad perspective.

There were two main approaches regarding the method of NOS teaching. At the beginning it was believed that students could gain understanding of science through engagement in inquiry activities. NOS was taught implicitly in science classes. Students were expected to learn NOS as a result of scientific activity, such as inquiry, held in class. In the last two decades, research revealed that a comprehensive approach supports that NOS should be taught explicitly (Akerson, Abd-El-Khalick, & Lederman, 2000; Khishfe & Abd- El- Khalick, 2002; Schwartz et al., 2004) and students understand science through the instruction of NOS as knowledge of NOS.

Norman Lederman and his colleagues have spent an extensive effort on NOS studies in order to understand the effect of NOS instruction on student learning and science teaching. In a study designed to investigate how NOS can be taught through inquiry, researchers proclaimed that inquiry could not enhance individuals' NOS understanding if NOS is taught implicitly (Schwartz et al., 2004). In other words, they claim that a person will not learn about the desired NOS concepts, if the person has not been explicitly taught these theories of NOS. Their most important contribution to the NOS studies might be the instruments that they developed and the studies that applied this instrument to different groups of people within different contexts (For details see the set of NOS dimensions taken from the VNOS- B questionnaire presented in the article authored by Lederman et al. 2001). However, the understanding of NOS was still structured and was assumed to be context independent. In other words, they assumed that there was a universal understanding of science that could fit to all science majors.

On the contrary, there are also some alternative approaches and studies supporting more flexible NOS categories that can be adapted to different contexts. These flexible categories are removed from being structuralist in their claims. For example, consider a study conducted in 2003 by Osborne, Collins, Ratcliffe, and Duschl. In this study, participants were selected from a pool of science educators and scientists to answer questions and discuss the NOS that should be taught in school. These researchers concluded that 18 distinct NOS categories emerged from interviews. Results of the qualitative analyses revealed new categories and several subcategories regarding NOS, including Science and Technology, Moral and Ethical Dimensions in the

Development of Scientific Knowledge, Empirical Base of Scientific Knowledge, Cumulative and Revisionary Nature of Scientific Knowledge, Observation and Measurement, Characteristics of Scientific Knowledge, and Specific Methods of Science. These categories were different from the previous studies.

Another study engaging students in different age groups was conducted in England by Driver et al. (1996). These researchers used different lenses to learn about students' images of science by looking at their views of the domains and the purposes of the scientific activity, the nature of scientific knowledge claims, and the nature of the personal and the social processes. Driver et al. (1996) concluded that students' understanding of NOS could be described by the type of reasoning the students used (i.e., phenomenon-based, relation-based, or model-based reasoning frameworks). This schema for categorizing students' conceptions of the NOS were quite different from Lederman's NOS categories.

A different approach was also used in McComas & Olson's (2002) book, *The Nature of Science in Science Education: Rationales and Strategies* (McComas, 2002). McComas & Olson (2002) examined various educational standard documents and curriculum materials in science education that are used in different locations of the world. Research results revealed few consistencies with NOS and its components, which were reflected differently in different curriculum documents.

No complete agreement on NOS themes exists among researchers (McComas, Clough, & Almazroa, 2002). However, the importance of NOS instruction is clear when it comes to teaching science. To sum up, there are multiple ways to describe NOS.

However, two main approaches were taken by researchers in attempting to describe NOS. The first approach established that *explicit was* more structured and allowed researchers to evaluate and measure the level of NOS in a given sample or in a represented population. However, this approach denied the context dependency of science completely and assumed that all science domains shared a common nature and culture and acted in the same way. More recent studies, however, have revealed that the NOS categories or dimensions change depending on the subject studied (Cetin, Erduran, & Kaya, 2010; Wong & Hodson, 2008, 2010). Thus, while approaches that are contradictory to conservative NOS understanding require more time during data collection, they allow researchers to be more flexible in research design. In addition, these differing approaches can provide extensive information regarding context dependency and variability of the NOS, and these approaches can explain science through a pluralist perspective. This allows us to involve and explain different forms of sociology and cultures of science depending on the content and the norms of the activity.

Philosophical debate about the NOS. After almost half a century of experience, there are still philosophically gray areas in NOS studies despite the hundreds of studies that have been completed. In the last decade, new alternative ideas and critiques among philosophers and science educators began to emerge. For example, in his study, Alters (1997b) found that philosophers did not agree with the NOS themes, even though it was assumed educational researchers would agree upon those themes. He was interested in investigating 210 philosophers of science and their views about NOS tenets commonly held by educational researchers. According to the results, there was no agreement among philosophers of science on the existing NOS taught in science education.

Two years later, in an article written by a group of philosophers (Eftin, Glennan, & Reisch, 1999), they perceived science from a family resemblance perspective and the assumption of a unified NOS understanding was an essentialist view of science. They mentioned "just as science educators stress the science is more than a collection of facts, we emphasize that a philosophical position about the nature of science is more than a list of tenets" (p.112). Researchers also added that they were not experts in science pedagogy, but they were familiar with the issue because of their experiences of teaching NOS to their students.

In his recent article, Michael Matthews (2012) explained the problems of NOS from a historical and philosophical perspective. According to Matthews (2012), considering different aspects of sciences such as their history, practices, and achievements, some features are common and shared, while some features are even not shared at all. Matthews suggested that NOS should not be understood as a list of knowledge posted on school walls because contemporary NOS understanding (1) puts epistemology, sociology, and philosophy together, (2) keeps one idea of NOS, which is still debatable, something absolute and giving more importance to methodology of science, (3) assumes there are specific solutions to the problem, and (4) assumes learning NOS can be assessed and evaluated based on students' statements about NOS.

Matthews also claimed that the view of NOS could be named as *features of science* instead of NOS and this general definition of NOS could capture epistemology and sociology of science together. As a result, the author suggested a need for change from NOS to features of science that can capture commonalities and differences among science majors and offer a more unstructured understanding of science to students, teachers, and educators.

Irzik and Nola (2011) also proposed an alternative approach to the universal understanding of science, which they called a consensus view. According to them, the theory of family resemblance surmounts what we called *nature* of science. Wittgenstein's family resemblance theory claims that the things we think to be connected by one common feature can be connected by various similarities instead of a single communality. That is to say, although there are some common things in NOS that we teach in school, it does not mean that it is universal and applicable in any context.

Recently, Duschl and Grandy (2012) proposed a synthesized version of the NOS by combining methodology and philosophy into one approach. These authors argued that due to the recent developments in cognitive, social, and educational sciences, there should be an emphasis on domain specific core ideas and science practices, instead of a domain general idea of science assumed to fit all. According to Duschl and Grandy (2012), there are two alternative views regarding the explicit NOS teaching instruction that meets the needs of the field. The first view mainly focuses on domain general consensus, and it is based on NOS teaching in science courses and activities. According to this theory, there is a list of NOS themes that has produced a consensus among philosophers, science educators, and scientists (Lederman et al., 2002; McComas & Olson, 2002; Osborne, Collins, Ratcliffe, Millar, & Duschl, 2003). In other words, students learn NOS better through instruction rather than making inferences of extrapolating what science is through inquiry. According to Duschl and Grandy (2012), this assumption is true when we discern science should be taught as single hour discrete inquiry sessions rather than teach science through unconnected facts and traditional teaching techniques.

However, today's science teaching is getting away from the traditional science understanding and structured inquiry approaches and is moving to more open-ended inquiry activities aiming to reflect the essence and culture of science (Duschl & Grandy, 2012). This is especially true in countries like the United States, which has prepared detailed frameworks and work plans, such as NRC (2007, 2012) to spread this approach by focusing on core concepts, science practices, and science as a culture and a discourse. For instance, NRC (2012) developed a new framework transforming science teaching for the 21st century. The new framework focused on domain-specific concepts and core ideas regarding physical sciences, life sciences, earth and space sciences, and engineering and technology applications. Also, the Taking Science to School framework (National Research Council, 2007) argued that students should learn science by (1) building models and theories, (2) using argumentation, and (3) engaging in scientific discourse.

As a second version of explicit NOS teaching, Duschl and Grandy (2012) suggested that students should use scientific knowledge and participate in science. For them, in version two, the term *explicit* refers to students' engagement and immersion in NOS, including science practices rather than direct instruction of NOS themes. We should notice that their explanation is different and does not mean that when students participate in inquiry, they learn the meaning and intricacies of science. Instead, they explain the explicit teaching of NOS is prompting students to engage in epistemological, cognitive, and socially structured inquiry activities, which are reflecting authenticity and a culture of science.

Scientists' Views of NOS

"Whose nature of science?" This question still needs to be answered (Eftin et al. (1999). To be able to answer this question, scientists' view of science has become an important topic of the NOS to gain first-hand information from the practitioners of science in the last decade. As members and practitioners of the science community, scientists have more experience with science than any other people because they are the experts (Schwartz, 2012). Our understanding of NOS also depends on inputs from scientists, as well as philosophers, historians, and educators' expertise. Input is required from these groups of people to transfer NOS into the curriculum (Matthews, 2009). "Tapping into scientists' ideas about what science is and how scientists do their research can be a valuable way to better understand the [NOS], the scientific community, and how authentic experiences might shape ideas about science" (Schwartz, 2012, p. 183). If educators want to design more authentic science learning experiences for students, they should design learning contexts similar to the way the experts work in the field (Barab & Hay, 2001). "Authentication is actualized through individuals' perception in tasks and practices of value to themselves and to [a] community of practices" (Barab, Squire, & Dueber, 2000, p. 37). We must take into account the way scientists do experiments, construct and manage their laboratories, and the way they function in socio-political and cultural systems (Eftin et al., 1999). Furthermore, if students will learn the basic construction of science, they would see that science is something that people do and is true because it is convincing. They will also see that science is not accepted as an outer reality as being true (National Research Council, 2007). Therefore, scientists' views of science can be important for science educators to hear and understand from the perspective of practitioners of science, who serve as a social and cultural entity.

However, "relatively few empirical studies have been conducted from a science education perspective that explore how scientists describe 'what science is' and the development of scientific knowledge" (Schwartz, 2012, p. 184). Also, it may be easy for a scientist to answer the question 'What is science?' (Schwartz, 2012). In addition, interviewing or surveying scientists about NOS is important, but should not be privileged as the only data source (Abd-El-Khalick, 2011). In this sense, case studies allow us to learn from scientists' unique expressions about their work (Schwartz, 2012). Further research should explore the effectiveness of using scientists' case studies to advance learners' conceptions of NOS and the nature of scientific inquiry. Additionally, "research is needed to uncover scientists' views of NOS and their stories that exemplify contemporary science practices, science progress, and the blurring boundaries at the cutting edge" (Schwartz, 2012, p. 187).

In 2003, Osborne et al. (2003) conducted a Delphi study entitled "What ideas-about-science should be taught in schools science." The purpose of the study was to empirically investigate the level of a consensus among scientists, science educators, historians, philosophers, and science sociologists, and other experts who worked in NOS related fields. Researchers used the Delphi study technique where data were collected systematically through questionnaires and feedback was given at different levels of the study. In this study, five of the participants were scientists selected from the Royal Society. Based on the results of the study, the researchers found nine refined categories that corresponded to sub dimensions of ideas about science. The nine themes (Osborne et al., pp. 706-709, 2003) are respectively as follows;

1. Scientific Method and Critical Testing
2. Creativity
3. Historical Development of Scientific Knowledge
4. Science and Questioning
5. Diversity of Scientific Thinking
6. Analysis and Interpretation of Data
7. Science and Certainty
8. Hypothesis and Prediction
9. Cooperation and Collaboration in the Development of Scientific Knowledge

Osborne et al. (2003) compared results among and within the group variances. They found no difference among the groups. Within each group, differences were relatively small and less than one, except reviseability and empirical bases of scientific knowledge among scientists. Researchers' first conclusion was that they had nine themes regarding views of science on which the experts agree. However, they also explained their concerns about those themes and stated "…findings might be seen to give legitimacy to decomposing the nature of science into a set of atomistic components that might, at worst, be taught in isolation in a highly decontextualized manner." (Osborne et al., 2003, p.712). This statement is important for the underlying idea of this study, because I hypothesize that without authenticity and a relevant context, teaching what science is as a list of themes will not be enough to reflect the essence of authentic science to students.

Schwartz and Lederman (2008) conducted a study to examine scientists' views of the NOS and explored how the NOS was related to the science context. Their primary research question was to explore scientists' view of the NOS and scientific inquiry. Their secondary objective related the NOS to scientists' science disciplines to see if it was domain specific or domain general. The research design was based on a phenomenological approach of qualitative research. The data were collected through open-ended questionnaires and interviews. The sample was 24 practicing scientists, who had doctoral degrees, had a minimum of two publications over a two-year span, and had been working in the United States. Participants were selected from physics, life sciences, chemistry, and earth and space sciences. VNOS-Sci and VOSI-Sci were developed by a panel of science educators and scientists for validity; these open-ended questionnaires were used as primary instruments. Researchers electronically sent the two instruments to the scientists. Twenty-three out of the twenty-four participants were interviewed via telephone or face-to-face; the type of interview depended on the location of the participant. Researchers used a discipline-based categorization to analyze their data. For this purpose, a group of researchers were divided into four categories labeled as experimental, descriptive, experimental/descriptive combination, and theoretical. The researchers were categorized into a group that was dissimilar from their background. In the initial phase of the study, there were 14 themes; however, two additional themes emerged. Seven of the 16 main themes were reported in detail and were as follows:

1. Scientific knowledge is tentative
2. Scientific knowledge is subjective
3. Scientific knowledge is empirically grounded
4. Role of creativity
5. Socio cultural influence on construction of science
6. Scientific theory and scientific law
7. Role of observation and inference

However, the researchers did not examine the 16 categories to correspond them to the sub categories. Instead they converged 16 main themes with Lederman's seven NOS themes and discussed the details in the seven categories. Although they proposed that they used a phenomenological approach in their design, it was understood that they used preexisting categories and tried to compare responses with those seven themes of Lederman (Lederman et al., 2002). The results of the study revealed that scientists' responses regarding the NOS were complex and had multiple dimensions. According to Schwartz and Lederman (2008), " The results demonstrate [a] connection between *individual* authentic scientific contexts and these scientists' views of NOS" (p.762). In other words, results had indicated a context dependent upon an NOS understanding of science. They also stated that they did not find any relationship between scientists' NOS views and the science discipline. However, they claimed that they found consistencies in the descriptions on a broad level and "on the level of broad generality" (p. 762).

The NOS views did not differ among the scientists' discipline. According to the researchers, since scientists' descriptions were very specific to their research, a number of participants under each sub dimension might be too small to identify a pattern. They also mentioned that scientists did not show any epistemological standpoint that could be classified as naïve or informed. As a result, they concluded that scientists' views of science were specific to their context and did not portray a pattern across different science disciplines. Thus, a domain general NOS should be taught to K-12 students at schools in order to be inclusive to other disciplines. They thought that if one approach was used to teach the NOS, it might not be able to represent interconnections among the disciplines.

That study was conducted to represent scientists' views of science and their relation to the context. However, the categories were mainly created based on the dimensions of the instrument conceptualized many years prior to this study. This might be a limitation for the study with respect to the nature of phenomenological study. Another limitation is that although it was stated that the number of participants was not big enough to make implications, the theorized outcome of the study was too general. It was even presented as a fact and recommended to K-12 education. In other words, having no pattern within a science discipline has been offered as inapplicable to school science, whereas differences among them were assumed to have a broader generality to

K-12 education. As a result, although this study did not present new themes or dimensions about the expert's scientific views, the sample quotes and codes explained have provided detailed insight regarding how the experts explain and defend their ideas about NOS.

Another study investigating scientists' view of science was published by Wong and Hodson (2008). The foundation of the study relied on some assumptions. The NOS had been one of the major goals of science education. It lacks a consensus and a robust understanding among researchers. The question of whether there was a universal NOS understanding or if it was context dependent has not yet been answered. Thus, according to Wong and Hodson (2008), scientific experts could play an important role by explaining their views of authentic science. Considering these, the purpose of the study was to investigate whether there were communalities and differences among the scientists' views of science regarding scientific investigation and scientific knowledge. Thirteen scientists accepted participation in the study. Scientists were located in the U.S., the U.K., Switzerland, and China. The scientists' experience ranged from 10 to 32 years. Except one participant, 12 of them were male. Participants were selected through purposeful and convenient sampling, and a case study approach was used. Data were collected through interviews and administering an open-ended questionnaire, which was a modified version of the VNOS. The interviews, which were videotaped or audio recorded, took between 80 to 180 minutes. Analysis yielded 8 categories regarding the scientists' understanding of science. These were, respectively:

1) Method of scientific investigation

2) Significance of theory in scientific inquiry
3) Tentativeness of scientific knowledge
4) Creativity in science
5) Social, political, economical, and cultural influence on science
6) Research funding issues, ethics, and academic freedom
7) Collaboration and cooperation
8) Role of peer review (Wong & Hodson, 2008)

A comparison of scientists' responses regarding those categories revealed that although scientists shared common ideas about NOS dimensions, their responses were more context-dependent and changes depended on personal experiences in that field. For example, although all scientists agreed that creativity was important during the process of knowledge construction and absolute objectivity was impossible, a group of scientists did not even consider the differences between theory and law before participating in the study. As a result, scientists' responses about the NOS aspects of their own research provided a view of science from the practitioners' perspective that could be useful for future studies completed by educational researchers. Wong and Hodson (2008) concluded that according to their study results, there was no single set of NOS elements that could fit into all science disciplines and context.

In another study, Wong and Hodson (2010) investigated what scientists said about science as a social practice. Basically, the study was the continuation of the previous study and they were now looking to scientists' views of science from a sociological and cultural perspective. Wong and Hodson (2010) explained the purpose of the study was to investigate the views of scientists with respect to the social and cultural embeddedness of science and compare it to the views held by science educators. Fourteen scientists from various disciplines were invited to participate from different countries for the study. Their experience in science ranged from 10 to 47 years. Eleven of these scientists worked in more than one country. The primary source of the data were open-ended VNOS questionnaires in addition to 90 to 180 minutes of face-to-face and phone interviews. The analysis yielded eight sub categories at the beginning, and they were collapsed under two main themes regarding culture and sociology of science. The researchers crosschecked their analysis and made decisions on resulting themes.

The results of the study revealed that scientists thought social, political, economical, and ethical factors determined the priorities of the research. Second, they agreed and reported that when scientists' work as members of a team, then the priorities are both competitive and collaborative. The scientists also agreed that the practitioners of science highly depended on others' work and knowledge. The researchers also reported that the context of science including its aims and instruments together affected the culture and understanding of science. According to scientists' responses, Wong and Hodson thought that scientists could make serious or trivial mistakes at times. Based on the study results, researchers suggested that in addition to robust NOS themes, sociology, culture, and anthropology of science relating to the context should be included in the education of science.

What Is the Contemporary View of Science Education?

Student-Scientist Partnership

In the previous sections, I have mentioned studies explaining scientists' contributions to science education and classroom science by providing an insight through their expressions about the underlying ideas of science, how scientific knowledge is constructed, and the culture and sociology of science from a practitioner's perspective. However, their contribution to science education is not limited to their reported views of science. In the past two decades, many attempts have been made to involve scientists in science education related activities. Scientists' contributions to science education have gone beyond just being a model for students. In the following paragraph, there will be a presentation of studies aimed at investigating scientists' partnerships with students in different activities.

For the development and integration of the 21st century skills into science teaching, involvement of scientists in science education will help students reflect the way the experts participate in science (National Research Council, 2010). Involving students in scientific investigations as part of a student-scientist partnership is an approach to introduce them to science practice (Lawless & Rock, 1998). As Akerson, Buzzelli, and Eastwood (2012) stated "…individuals gain knowledge of the physical and social world and themselves as active agents in the world through participation in different social groups and communities" (p. 136). Scientists' participation in science education and students' interactions with scientists may express science as a culture and a social entity, which includes these scientists. Rahm, Miller, Hartley, and Moore (2003) also proposed that:

> Authentic science is an emergent property of a dynamic system of learning precipitated by the interactions among students, teachers, and scientists that occur within the contexts defined by the internal and external constraints of the cultures of the schools and communities within which they operate (p. 737).

Moreover, since scientific research does not occur in a vacuum environment, it is normal for students and teachers to access someone like a scientist to discuss questions and concerns in formal education (Evans, Abrams, Rock, & Spencer, 2001).

As Barab and Hay (2001) explained, students in the classroom do not experience the practice of real science, the identity of being a scientist, and the authenticity of the studied cases. As a result, students are expected to internalize a scientific understanding wherein content was designed at school, but the purpose is to teach a science culture that is unique to the culture of science outside of the school (Barab & Hay, 2001).

> If we believe that the nature of science is necessary for scientific literacy and cannot be separated from the 'doing of science,' SSP [Student Scientist Partnerships] developers and teachers who implemented the SSPs must help students experience all the steps of scientific enterprise (Moss et al., 1998, p.160).

Lawless and Rock (1998) suggested that establishing a framework focusing on NOS for the partnership is important and it is one of the key elements of inquiry, like skilled and knowledgeable teachers and materials designed by educational researchers.

Currently, most science teaching takes place in science classrooms where students learn through direct instruction. For instance, a recent study revealed that more than 65% of the instruction in middle school science classes are teacher-directed activities such as lecture, demonstration, and teacher-led discussion (Tassell et al., 2012). In such an environment, opportunities for students to understand and internalize science as a culture and practice would be minimal and almost impossible. Therefore, the possible contribution of scientists needs to be investigated.

According to the results of the study, which is based on pre and post test, and data collected from more than 190 students in a partnership project, student-scientist partnerships significantly increase students' content knowledge and attitudes towards science (Houseal, 2010). Students' engagement in science projects is based on a student-scientist partnership model, which is mutually beneficial because it increases the students' content knowledge and skills when they experience science as it is practiced (Baumgartner et al., 2006). This model also changes students' perceptions about scientists, the possibility of choosing science as a career, and how to become a scientist by making them familiar with what a scientist actually do in a laboratory (Marx et al., 2006).

Positive effects on various aspects of science learning were seen in a recent empirical analysis of literature regarding the involvement of scientists and their partnerships with students in school education (Sadler, Burgin, McKinney, & Ponjuan, 2010). Sadler et al. (2010) conducted and published an empirical and critical review study to examine the effectiveness of apprenticeship programs in which students work with expert mentors and scientists on authentic science activities. In total, 53 articles focusing on science apprenticeship in middle school and high school were selected. Articles were analyzed by using a thematically qualitative approach. Overall, the results showed that studies reported a positive effect of apprenticeship on the several learning outcomes such as career aspiration, NOS, scientific content knowledge, confidence and self efficacy, intellectual development, skills, satisfaction, discourse practices, collaboration, and changes in teacher practices. However, they mentioned that some themes reported conflicting conclusions and there is a need for valid instruments and conclusions rather than researchers' interpretations. In addition, authors indicated that to promote a more advanced understanding of science, explicit statements of NOS dimensions, such as tentativeness and the role of creativity are required instead of expecting students to conceptualize science based on inferences or implicit statements. In this sense, Sadler et al. (2010) claimed that students' epistemological engagement in the process is critical to accomplish expected objectives.

For example, in a study, student-directed constructionist inquiry activities and scientist-mentored authentic inquiry activities were compared. These two types of activities were designed as a summer camp; participants were high school students, scientists and teachers (Hay & Barab, 2001). According to Hay and Barab (2001), students in scientist-mentored activities had a greater advantage of understanding the scientific practices and authenticity of science compared to those who performed student-directed inquiry activities. They also described that the scientists' participation could be applied in two different ways in terms of how we set up the learning environment and where and how authenticity is achieved. Hay and Barab (2001) explained the two main approaches as *simulation model* and *participation model*. " The simulation model is predicted on the assumption that the classroom environment (both in terms of the goals, practices, instruments, and peers relationship) should be made as similar to communities of practice outside of school as possible" (Barab & Hay, 2001; p. 74). On the contrary, the underlying assumption and purpose of the participation model is to make students engaged in experiencing science with scientists, or as Hay and Barab (2001) called at the elbows of scientists, in their laboratories and fields.

Student-scientist partnerships can also provide solutions to the implementation of inquiry in the classroom. Edelson, Gordin, and Pea (1999) defined five challenges of implementing inquiry-based learning as (1) motivation, (2) accessibility of investigation techniques, (3) background knowledge, (4) management of extended activities, and (5) practical constraints of the learning context. A recent study revealed that scientists in a student-partnership model can support students in all dimensions which are challenges of inquiry based learning by motivating, serving as a knowledge source, designing experiments, following the procedure, and reflecting on scientific knowledge (Scogin, Ozturk, & Stuessy, 2013).

In application, student-teacher partnerships have also been found to be beneficial to students even at a minimal level of science activity. For example, Akerson et al. (2012) claimed that:

> The combination of viewing films that include scientists and searching for stereotypes, interviewing a scientist, and developing a "culture of a scientist"

> notebook seemed to provide the reflexive experiences that enabled the preservice teachers to see scientists differently – to see them as not a foreign to themselves culturally (p.153).

As seen from the example, even interaction without doing inquiry can inform individuals about a culture of science. A well-designed, one week science camp in which students work with real scientists and science practitioners also improves students' understanding of science at some level, such as the inferential use of data and the process of science (Fields, 2009). Those interactions with scientists can be a motivating factor for students to move them from being outsiders of science to practitioners of science. According to Barab and Hay (2001) in a learning environment "newcomers' primary motivation for learning involves participating in authentic activities of community and in doing so, the new comer move towards becoming more central to the community of practice" (p.72).

Learning opportunities that support students' participation in doing science with scientists should be provided to accompany the formal school science by including activities towards the building of concepts (Barab & Hay, 2001). Moreover, student-scientist partnerships reveal to students that science is a human endeavor and construct. For instance, students believe that scientists do not use their creativity and science only seeks the truth (Akerson & Abd-El-Khalick, 2005). To the students, this means that imagination and creativity are not science related, and that scientific knowledge consists solely of facts and truths.

Recent studies focusing on student-scientist partnership programs showed that students' participation in apprenticeship programs not only introduces them to the culture of science, but also affects their inquiry skills and understanding of science or the NOS. For example, Aydeniz et al. (2011) investigated the effect of apprenticeship-based research programs in which school students work with scientists on authentic science activities. They found that apprentice programs had an effect on students' inquiry skills and the understanding of NOS. At least 75% of students developed a sophisticated NOS understanding after their experience with scientists. They demonstrated significant changes in 10 of the 14 NOS dimensions. The changes were seen in the following dimensions: the role of creativity into the work of scientists, the precision during data collection, empirically based nature of scientific knowledge, subjective and tentative NOS, and the difference between experimentation and observation. However, students reported a low level of sophistication (less than 30%) in three NOS dimensions: unexpected results, process of theory formation, and role of hypothesis in scientific inquiry. The authors also added that the students developed sophisticated NOS understandings when they were explicitly informed by the experts.

These findings highlighted how student-scientist interactions can enhance students' understanding of science by using explicit NOS discourse. Another example is that error in science is a key incident to teach the NOS because error types reflect the corresponding methodologies, critical analysis, and discussion of practiced science (Allchin, 2012). A recent study (Scogin et al., 2013) showed that scientists in an online partnership may contribute to NOS by discussing the error in science and the nature of error as a part of their dialogues with students.

Scientists' support of student learning can also be explained by the term "cognitive scaffolding" as described by Goldman, Petrosino, and Cognition and Technology Group at Vanderbilt (1999). Cognitive scaffolding refers to various forms of cognitive guidance and support. "Cognitive scaffolds are analogues to actual physical scaffolds used in constructing buildings. …the supports are temporary and are removed as the building is completed. Likewise, cognitive scaffolding provides a support structure for thinking" (p. 607). In this sense, scientists' interactions with students, who are novices, can enhance and support students' views of science by providing them the nature and the process of science.

Historically, the idea of cognitive scaffolding originates from the concept Zone of Proximal Development (ZPD) proposed by Lev Vygotsy (1978). ZPD refers to the idea that any child has a potential mental function and it can be increased as he interacts with adults, experts, and peers (Vygotsky, 1978). Vygotsky's theory stresses the importance of social interaction in a child's cognitive development. Vygotsky developed his theory based on a socio-cultural approach unlike Piaget's constructivism. For Vygotsky, an individual's development is an outcome of his or her culture. A child's abilities develop through social interactions with others and, therefore, represent the shared knowledge of the culture (Vygotsky, 1978). Vygotsky explained cognitive development as a child learns through problem solving experiences with a friend, teacher, or parent. During the problem solving process a child develops an intellectual transformation through the use of language and the learning processes. In other words, Vygotsky (1978) mentioned that when practical activity and discourse converges, it results in intellectual development. Vygotsky also stated that learning is a type of cultural adaptation occurring in not only the culture of the environment, but also including knowledge and tools existing outside the child.

Considering the social constructivist theory perspective, one of the most important implications of scientist-student partnerships is that student-scientist partnerships allow students to participate in scientific discourse through inquiry. Baker et al. (2009) explained this concept as “science classroom discourse community,” which is created as a part of science culture, and it promotes scientific discourse, scientific habits of mind, and language acquisition. Active participation in discourse is central to science learning and science education (Newton et al., 1999). Duschl and Osborne (2002) clearly stated the importance of students’ participation in scientific discourse and discussed that:

Developing an understanding of science and appropriating the syntactic, semantic and pragmatic components of its language requires students to engage in practicing and using its discourse in a range of structured activities. Only such tasks will support the social construction of knowledge, exposing student thinking and enabling its critical evaluation by the teacher, the student and his or her peers. (p. 41). However, research results revealed that classroom discourse was dominated by teachers rather than students (Duschl & Osborne, 2002; Newton et al., 1999). Furthermore, because teachers are not subjected to discourse practices of the scientific community, modeling discourse practices and how to reflect the discourse practices of science in science classroom is still problematic (Duschl & Osborne, 2002). Based on their study about the state of discourse in K-12 education, Newton et al. (1999) recommended three main discourse models which were respectively: a *transmission model—e*xplaining science as body of facts taught by authority; a *discovery model*—explaining science as body of knowledge, laws, and theories learned through experience; and a *social constructivist model*—defining science as reasonable explanations of phenomena accessed through discourse and argumentation. Newton and his colleagues strongly recommended the use of the social constructivist model and creating discourse opportunities for students.

For the past 20 years, research has indicated that practicing something does not assure developing an epistemological understanding (Schwartz, Lederman, & Abd-El-Khalick, 2012) and engaging in inquiry did not mean students develop a deep understanding of science (Lederman, 2004). According to Duschl (2008), the change or the shift in science education requires the design and development of new learning environments that are centered around research of understanding NOS and of participating productively in scientific discourse in science teaching and learning. "Opportunities for students to engage in collaborative discourse and argumentation offer a means of enhancing student conceptual understanding and students' skills and capabilities with scientific reasoning" (Osborne, 2010, p. 463). In addition, science classroom discourse communities create opportunities for students to communicate, create, interpret, and critique scientific arguments using scientific explanations and data obtained from inquiry activity (Baker et al., 2009). Our explanations, whose evaluation and construction involve our scientific argumentation, are central products of science (Sandoval & Millwood, 2005).

A recent study indicated that reflexive NOS instruction and discourse, which were explicit and integrated, provided gain in high school students' NOS conceptions (Eastwood et al., 2012). A pretest-posttest control-group design study with 30 eighth grade students revealed that reflective discussion about NOS following inquiry activities enhanced students' NOS views more than just involving inquiry in laboratory settings (Yacoubian & BouJaoude, 2010). Therefore, scientists' dialogue and interaction with students about the nature and the process of science can be a fruitful environment for students.

Although the number of studies focusing on student-teacher partnerships increase, the research on interaction between students, teachers, and scientists is limited. Recently, Peker and Dolan (2012) conducted a study investigating in-depth practices of scientists and teachers as they helped students during authentic inquiry activity. The data were collected from 40 students from three classes in two high schools. As scientists and students engaged in partnerships together with the teacher, their interactions were captured through video and audio recordings. Then, the researchers used conversational analysis to examine naturally-occurring dialogues mainly between students and scientists.

According to the results, scientists and teachers used several strategies and functions to support students' meaning-making. These strategies and functions were (1) increasing the conceptual understanding, (2) playing the role of knowledge authority, (3) promoting the idea of scientific community, (4) organizing ideas, (5) increasing accessibility of knowledge, and (6) checking students' knowledge and offering ways of knowing. Different from teachers, scientists provided epistemological and pedagogical aspects of meaning to help explain the aspects of NOS and natural phenomena. Finally, authors (Peker & Dolan, 2012) suggested that scientists and teachers together could assist students' meaning-making during authentic inquiry activities in the science classroom. The sociocultural perspective of science was one interest of the study, because as Lemke (2001) explained "…scientific study of the world itself [is] inseparable from the social organization of scientists activities…"(p. 296).

Thus, scientists' naturally occurring dialogues and their expressions of science can be an important source of data for science educators to interpret the direct conversations between students and scientists without a shred of the assumptions that have been made about the NOS. Moreover, communities such as classrooms, online communication forums, and collaboration environments provide us tools like specialized discourse and practices to understand the social perspective of the community around us (Lemke, 2001).

Technology and Partnership

Today's technologies, especially web based ones, offer opportunities for both students and teachers to engage in authentic activities, learn content, and be a part of student-scientist partnerships (Edelson, 2001). New technologies mentioned here do not refer to the use of computers and technological materials, such as power point presentations and smart-board applications in classroom, but they do refer to the computer technologies and tools that involve inquiry and make students experience science authentically. These types of technologies are called “information and communication technologies” (ICT). ICT usage in science education in the middle and secondary schools offer a sense of participation and a collaborative working environment that allow students the opportunity to learn and experience all stages of scientific inquiry (Barab & Dede, 2007). Technologies and designs like ICTs decrease the gap between the school science and the real science (Osborne & Hennessy, 2003). They allow students to access a broad range of data and manipulate variables of the real science issues in a classroom environment, such as real-time air pollution measurements and astronomical observations (Osborne & Hennessy, 2003).

Online inquiry environments that allow students to work with real scientists are among the technologies currently used in some projects around the world. One of the first early and large scale applications was the Global Learning and Observations to Benefit the Environment (GLOBE) project which has been used by 5,000 schools over 60 countries in K-12 education (Finarelli, 1998). In the GLOBE project, students took real time measurements through hands-on activities and shared the data with worldwide science communities via the Internet. In addition, the project website allowed students to communicate and collaborate with scientists and other students. The GLOBE project has initiated the idea of a large-scale student-scientist partnership in online environments.

As Wofford (2009) discussed in his review article covering the ten year span between 1998-2008, the use of computationally rich technologies in science education was effective in terms of improving students’ understanding of science. Although access to expert scientists is a critical element of student scientist partnerships, regularly updated websites and disseminating information electronically may improve student motivation when direct contact is not possible (Evans et al., 2001). A recent study (Liang, Ebenezer, & Yost, 2010) supporting my argument about scientists' contributions to students' online authentic science experiences found that pre-service teachers could provide collaboration and communication support through inquiry. The teachers could not be critical and were not able to evaluate the elements of science such as explanations and evidence like scientists do.

Technological tools may not be effective to introduce authenticity of inquiry to science classrooms. For example, a recent study conducted by Waight and Abd- El-Khalick (2011) exhibited the implications of a web-based tool used in the high school science classroom. This web-based tool is normally used by scientists in biology. The results show that students mostly spend time on following instructions and focusing on science content (Waight & Abd-El-Khalick, 2011). In addition, the activity lacked authenticity and was teacher-centered, which made authors suggest that the adoption of technological tools was needed to switch the focus from teachers' knowledge and skills to practicing the role of scientists and researchers. Recent research found that technologies, such as videoconferencing, were ineffective in terms of student participation and authenticity of the activity because students might not express themselves in front of a big group and might not engage in effective discussions after the videoconferencing (Falloon, 2012b).

From the student-scientist perspective, there are also some issues regarding the use of technology to implement authentic inquiry activities into the science classroom. A case study examining student-scientist partnerships in a high school showed that students believed the process of science only involves experiments and there is never communication between students and scientists (Moss, 2003). Besides, as found in another study examining student-partnerships, students' responses indicated a disconnection between themselves and scientists (Seraphin, 2010).

In this sense, a combination of both synchronous and asynchronous systems may have a role to facilitate interactions between scientists and schools. "Asynchronous systems enable scientists to timetable interaction around other commitments and develop more detailed responses, while synchronous tools support relationship establishment and dialogue, perhaps better promoting positive perceptions of scientists and their work." (Falloon, 2012, p. 6). Previous studies have revealed that student-scientist partnerships without communication do not reflect the NOS and do not accomplish attained objectives (Moss, 2001, 2003; Moss, Abrams, & Kull, 1998). Daniel Moss, in his study published in 1998, explicitly stated that one of the major issues in student-scientist partnerships was a lack of contact between partners, for scientists might not have time to visit the student to foster the partnership. He also suggested that web-based online environments could be used to enhance the partnership. These initial attempts to build partnership models between students and scientists made the picture clearer for future developers who learn from others' previous mistakes.

Falloon (2012a) conducted a study in New Zealand to develop an effective framework for student-scientist partnerships in the countries with institutions in which scientists were commonly employed. The study, which was based on both qualitative and quantitative data, indicated that science institutions strongly preferred to work with teachers by using technology as a medium to communicate, collaborate and support the science classroom.

As seen from the examples and study results, technologies that allow an effective student-scientist partnership exists. In the following section, one of these effective partnerships, *PlantingScience* will be explained in full detail. *PlantingScience* is an online mentoring platform that will be the basis for our study.

PlantingScience: An Online Student-scientist Partnership Model

In formal education, particularly, cooperation and collaboration, which are two important elements of authentic science, are not always easy to facilitate. Face-to-face partnership models including field trips and science fairs may be limited to a small group of students and scientists and cover a short period of time. The Botanical Society of America's *PlantingScience* project provides opportunities for plant scientists to contribute to science educators as role models and educators to present the authenticity of science, while the teachers and students in science classrooms across the world are the beneficiaries (Scogin et al., 2013). *PlantingScience* is a project supported by the American Botanical Society, the National Science Foundation, and other partners, including Texas A&M University. The project "makes science experts accessible to secondary school classrooms with the goal of improving understanding of science while fostering an awareness of plants" (Hemingway, Dalh, Haufler, & Stuessy, 2011, p.1535).

The *PlantingScience* project was awarded the SPORE award in 2011 by the American Association for the Advancement of Science (see Hemingway et al., 2011) for innovation in learning. The project's staff at the Botanical Society of America has assembled over 700 mentors from 12 different societies to partner with over 500 classroom teachers and 10,000 students. About 60% of the classes are in high schools, and 38% are in middle schools. College classes and 4-H clubs also participate. The society recruits and trains scientist-mentors, enrolls teacher-student teams to engage in the project, matches scientist-mentors with individual student teams, provides online materials including curriculum guides and assessment rubrics, and supports all participants as they engage in the blended learning environment, both the classroom-laboratory and the online communications platform.

The project also supports teachers' professional development in summer workshops where they receive first-hand experiences in designing open-ended inquiry projects enabling their students to think and work like plant scientists. In these workshops, teachers learn how to engage students in dialogue with a scientist-mentor who volunteers to communicate with each student-inquiry team through the use of an internet-based *PlantingScience* portal. A web-based portal allows communication within and across students, teachers, and scientist-mentors. While students design and complete their experiments, scientist-mentors communicate with them about the students' online entries in their laboratory notebooks, often asking questions about their scientific procedures and results.

For the students' experiments, the teacher provides laboratory and plant materials to use in hands-on investigations occurring within the regular science classroom. Teachers also assist students as they frame their own scientific investigations by generating student-driven scientific questions, designing methods for answering them, collecting and analyzing scientific data, and providing answers to the questions using the data collected as evidence. Besides, the use of the Internet-based platform also requires teachers' instruction, which may include posting data and results in an online laboratory notebook, summarizing experiments in final written products, and using the asynchronous communication blog supporting the communication of scientist-mentors and student inquiry groups.

On the *PlantingScience* platform, all student materials are available for the public to view. The public cannot, however, directly communicate with students because the online environment is password-protected to only allow teachers, mentors, and other student teams to privately engage in their own inquiry investigations. The general structure of the project enables scientists to do what they do best: contribute their own knowledge and experiences to novice learners from their perspectives as experts who "do science" in their professional lives. Fundamentally, *PlantingScience* is a partnership model enabling students to learn about science in ways beyond a typical school classroom experience. Through a blend of the "regular" classroom setting and the online portal, *PlantingScience* provides opportunities for scientists, teachers, and students to collaboratively engage in authentic science in ways benefitting all parties.

Putting It All Together

School science has had some problems in the past and will also struggle through difficulties in the future. Hence, approaching the most authentic science teaching should be our main goal as educators. Despite the discussions about explicit or implicit teaching of NOS, understanding of science can neither be left to students' ability to make inferences from what they see or do during inquiry activities, nor teachers' direct instructions about what science is as a general consensus view. Our philosophical standpoint needs to be shifted to a more pluralist and reflexive interpretation of science from structured positivist notions of science so that we can understand science as a human endeavor and social construct in addition to its core system. This is why, methodologically, present studies mainly rely on naturalist research results to understand the essence of individuals' understanding of science in addition to quantitative findings.

Engaging scientists who are practitioners of science in science teaching can be implemented for more developed science understanding. Students' participation in scientific discourse and their interactions with scientists familiarize students with the culture of science as a human endeavor. At this point, students' interaction with practitioners of science and being a part of a scientist-student mentorship is critical to proliferating firsthand information about the science and its culture. Research on teaching the NOS showed that the NOS instruction through the reflexive discourse makes features of science visible for students.

Scientists’ participation in science education activities and their contributions, however, mostly have been evaluated by pre- and post-test design and standardized instruments. The inclusiveness of which scientists reflect their understanding of science to the students were not yet explored. Previous research has focused on what scientists say about NOS in round table meetings where students were not part of the activity. Besides, scientists’ interactions with students did not go beyond short-term workshops and weekend science camps. However, in theory, students move toward the center of the community of science progressively over time, but not as a result of the short-term activities. It is vital to design more authentic environments that provide students opportunities to do science and create environments that are very similar to where scientists work. The implication of authentic activities can reflect the essence of science and the reality of culture and sociology of science, which is limited to the number of participating scientists and their interactions with a small group of students. Developing technologies allow students and scientists to communicate and carry out inquiry activities for long periods of time, record dialogues, and make the dialogues visible for the participants of the inquiry activities. Most importantly, in these platforms, scientists can reach vast amounts of students synchronously and asynchronously.

CHAPTER III

THE NATURE OF *PLANTINGSCIENCE*: FIRST HAND INFORMATION FROM STUDENT-SCIENTIST DIALOGUES

Introduction

Students in the classroom do not experience the practice of real science, the identity of being a scientist, and the authenticity of the studied cases (Barab & Hay, 2001). In such an environment, opportunities for students to understand and internalize science as a culture and practice would be minimal and almost impossible. In this sense, scientific inquiry has been proposed as one method of science teaching that has received support from national and international curriculum standards in the last decade to promote authentic science (National Research Council, 1996, 2000, 2012). However, inquiry can be challenging for teachers who lack confidence in presenting science processes and the nature of science to their students. An inquiry-based, online mentored learning platform called *PlantingScience* was developed by the Botanical Society of America to help address this problem. *PlantingScience* enables students to learn and get firsthand information about how science works and what scientists do. Through its online platform, it links real scientists to students in the classroom through an authentic student-scientist mentorship.

This study aims to investigate how scientist and students are engaged in scientific inquiry and in which ways they interact with each other in an authentic science experience through online communication. Revealing the educational, social, and cultural means of interaction in this student-scientist partnership can help us, as educators, to better understand the essence of nature and culture of science from practitioners' perspective.

A qualitative approach has been chosen to better understand the dialogues between students and scientists. The unit of analysis for this study is naturally occurring dialogues between students, who are groups of four in average, and an assigned scientist. The sample of the analysis was recruited from 36 inquiry groups, which included more than 140 students and 36 scientists. A grounded theory research approach with a constant comparison technique was used for the analysis of the data obtained from the student-scientist dialogues.

Research Questions

In the literature, there is a gap of information exploring how scientists reflect their understanding regarding the NOS. The above information and previous studies propose that research intends to investigate student-scientist mentorship by analyzing scientist-student dialogues. The aim of this particular study is to answer these questions:

1) How do scientists talk to students about the nature and features of science, specifically botanical science?

2) What do scientists say about science when they engage in online dialogue about students' inquiry projects?

3) What are the connections between scientists' demographics, the subject of the inquiry, and the way they explain the nature of science?

Theoretical Framework

Science education has encountered some systematic and theoretical challenges. For instance, much of what is currently taught in schools as science does not represent contemporary science practices (Falloon & Trewern, 2012). Students' experiences of learning science are inconsistent with respect to science topics and disciplines included (Shwartz et al., 2008). Controversy still remains as to whether school science should be taught to reflect the authenticity of true science (Lee & Butler, 2003). Furthermore, science teachers most commonly rely on teaching science the way it was taught to them, with expectations that students will "master" scientific information. In more traditional methods of teaching science, teachers pay little attention to students' understanding of science and scientific inquiry. For many students, however, the quality of their science experience in school is critical because their school experience may be the only formal exposure to science that they will receive in their lives (Moss, 2001).

The underlying reason behind these challenges could be explained by research findings centered on the nature of science and the nature of school science. Individuals engaged in laboratory-based ethnographic studies assert that authentic inquiry refers to the real world of science. Authentic inquiry is different from scientific inquiry inside the classroom in terms of norms, objectives, tools, application, and included characters (Latour & Woolgar, 1986). Scientific and authentic inquiries have some fundamental epistemological differences in addition to the definitional ones. For instance, according to an empirical study carried out by Chinn and Malhotra (2002), inquiry activities do not reflect the authenticity of science. Moreover, while science education standards and government related reports promote scientific inquiry as the goal of science teaching, science educators and philosophers all agree that science teachers are not well trained and lack an understanding of real or authentic science (Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000). In addition, most teachers possess naïve understandings of science that do not allow them to teach authentic science (Akerson & Abd-El-Khalick, 2005). Scientists, however, as members and practitioners of the science community, have more experience with science than any other people because they are the experts (Schwartz, 2012). Society's understanding of NOS depends on inputs from scientists, as well as philosophers, historians, and educators' expertise. Input is required from all of these groups of people to transfer NOS into the curriculum (Matthews, 2009). "Tapping into scientists' ideas about what science is and how scientists do their research can be a valuable way to better understand the [NOS], the scientific community, and how authentic experiences might shape ideas about science" (Schwartz, 2012, p. 183). "Authentication is actualized through individuals' perception in tasks and practices of value to themselves and to [a] community of practices" (Barab, Squire, & Dueber, 2000, p. 37). We must take into account the way scientists do experiments, construct and manage their laboratories, and the way they function in socio-political and cultural systems (Eftin et al. 1999).

For the development and integration of the 21st century skills into science teaching, involvement of scientists in science education will help students reflect the way the experts participate in science (National Research Council, 2010). Involving students in scientific investigations as part of a student-scientist partnership is an approach to introduce them to science practice (Lawless & Rock, 1998). As Akerson, Buzzelli, and Eastwood (2012) stated, "…individuals gain knowledge of the physical and social world and themselves as active agents in the world through participation in different social groups and communities" (p. 136). Scientists' participation in science education may introduce students to the culture and sociology of science, which includes scientists. Moreover, communities such as classrooms, online communication forums, and collaboration environments provide us tools like specialized discourse and practices to understand the social perspective of the community around us (Lemke, 2001).

The literature reveals that student-scientist partnerships increase students' attitude and knowledge towards science (Houseal, 2010), increase their content knowledge and skills (Baumgartner et al., 2006), changes student's perceptions about scientists, and the possibility of choosing science as a career (Marx et al., 2006). A recent empirical analysis of literature regarding the involvement of scientists and their partnership with students found positive effect of scientists' involvement in science teaching on various aspect of science learning (Sadler et al., 2010). Recently, Peker and Dolan (2012) conducted a study investigating in depth practices of scientists and teachers as they help students during authentic inquiry activity. These researchers used conversational analysis to examine naturally occurring dialogues between students, scientists, and classroom teachers. According to the results, scientists and teachers used several strategies and functions to support students' meaning making. Scientists' functions varied from increasing conceptual understanding, playing the role of knowledge authority, promoting the idea of scientific community to organizing ideas, increasing accessibility of knowledge, and checking students' knowledge and offering ways of knowing. Different from teachers, scientists provided epistemological and pedagogical aspects of meaning making such as explaining the aspects of nature of science (NOS) and natural phenomena.

Methods

Study Context

The Botanical Society of America's *PlantingScience* project provides opportunities for plant scientists to contribute to science educators as role models and educators to present the authenticity of science, while the teachers and students in science classrooms across the world are the beneficiaries (Scogin et al. 2013). *PlantingScience* is a project supported by the American Botanical Society, National Science Foundation, and other partners, including Texas A&M University. The project "makes science experts accessible to secondary school classrooms with the goal of improving understanding of science while fostering an awareness of plants" (Hemingway et al., 2011, p.1535). Fundamentally, *PlantingScience* is a partnership model enabling students to learn about science in ways beyond a typical school classroom experience. Through a blend of the "regular" classroom setting and the online portal, *PlantingScience* provides opportunities for scientists, teachers, and students to collaboratively engage in authentic science in ways benefitting all parties.

Qualitative Research Strategy

For the current study, a grounded theory approach was used. According to Corbin and Strauss (2008): "Qualitative research allows researcher to get the inner experience of participants to determine how meanings are formed through and in culture, and to discover rather than test variables" (p.12). As the research aims of this study are to investigate the naturally occurring dialogues between students and scientists with an emphasis on their talk about science, grounded theory was used for two main reasons. First, there is no theory in the literature about how scientists talk about science in a student-scientist partnership. Second, the context of the study is a bounded system that includes different actors and a specific culture based on idea share and discourse, thus, grounded theory is the best fit when the research questions were taken into account. Moreover, the role of the theory in social research is to handle data, provide conceptualizations, descriptions, and explanations (Glaser & Strauss, 1999). Grounded theory provides hypotheses for future research to be verified, and appropriate, clear and operationalized categories to be used in quantitative studies when needed (Glaser & Strauss, 1999). Typically, quantitative research uses existing theories in literature and most of them do not aim to test the theory. Instead, it verifies and generalizes findings by using the theory. There are many theories in the literature that have provided basis for many studies. Nevertheless, the theory is fundamentally bounded to the present data (Glaser & Strauss, 1999). As Glaser and Strauss mentioned, "grounded theory is derived from data and illustrated by characteristic examples of data" (p.5). Grounded theory is a process of research that involves generating a theory. To sum up, from a methodological perspective, grounded theory can be described as a "well-confined set of propositions or is a running theoretical discussion, using conceptual categories and their properties" (Glaser & Strauss, 1999, p. 31). In the light of above explanations, I believe the purpose of this study and aim of grounded theory seeks to describe a process completed by the participants are aligned with each other, which is very important in designing a qualitative research.

Role of Researcher and Researcher Background

Grounded theory is a qualitative strategy relying on theoretical sensitivity of researcher that is independent from a preconceived theory (Glaser & Strauss, 1999). Therefore, quality of this qualitative approach requires to be evaluated based on the "credibility" and "authenticity of findings" (Creswell, 2007; Lincoln & Guba, 1985; Whittemore, Chase, & Mandle, 2001). To be credible, Creswell (2007) suggested that the researcher needs to base his/her findings on prolonged engagement, persistent observation in field, and knowledge of the culture studied. In this study the role of the researcher is important in two ways. First, I have been trained as an educator for 15 years since high school. I have teaching degrees in science and mathematics education and a Master's degree in science education and am seeking a Ph.D degree at the time of the study. During my doctoral study I have been trained through basic and advanced level qualitative research courses with an emphasis on field study and ethnography. I believe that my background in education and qualitative studies together strengthens me as the researcher of this study.

Second, as a member of the BSA Research Team I have had prolonged engagement in the project as an active participants for over three years. As a researcher I have been inside the classrooms implementing *PlantingScience* , carrying out several classroom observations in several states for the *PlantingScience* project, and I have observed students as they have worked with the *PlantingScience* curriculum modules. I met *PlantingScience* scientists and teachers as I attended workshops and summer camps with them. In addition, I have studied scientists' dialogues in different studies for the project. These experiences have helped me develop a familiarity with the project context and its culture. Many of the members of the BSA Research Team formed collegial relationships with both the teachers and some of the scientists in the project. This also helped ensure our understanding of scientists' views. Specifically, analyzing asynchronous dialogues allowed me to identify details of the discourse and who told what and how it changed through time, particularly as the online dialogues were recorded in such a way to allow us to collect information about details of the online discourse between scientists and students.

Procedure

Online dialogues between students and scientist generated throughout students' scientific investigations posted to the *PlantingScience* platform were used as data sources. Conversations of student teams were the units of analysis. I randomly selected naturally occurring online dialogues between students and scientists from a pool of 100 student teams participating between spring 2011 and spring 2014 in the project. A random number generator was used to select the groups. I downloaded each groups' project web pages including dialogues and hosted on the *PlanitngScience* server. In addition to digital copies, I was therefore able to obtain and print hard copies of students' dialogues for data analysis. In total, I obtained and analyzed 312 pages of student-scientist dialogues.

A theoretical sampling approach (Glaser & Strauss, 1999) was used to collect data from a homogenous group. The number of teams chosen out of 100 students teams was defined based on the theoretical sampling principle. Theoretical sampling is a data collection method based on concepts derived from data (Corbin & Strauss, 2008). Corbin and Strauss stated that "The purpose of theoretical sampling is to collect data from places, people, and events that will maximize opportunities to develop concepts in terms of their properties and dimensions, uncover variations, and identify relationships between concepts." (p.143). The point at which we stopped including new cases was defined by another principle, theoretical saturation, which is unique to grounded theory research. Theoretical saturation refers to the process of selecting cases for analysis until no additional data are found that enables the researcher to develop new categories in analysis (Glaser & Strauss, 1999). Theoretical saturation was reached after the analysis of 36 groups.

Scientists' occupations were classified under three categories: (1) university-affiliated (university professors), (2) non-university affiliated (scientists who work in NGOs, private sector, and governmental organizations) and (3) graduate students. Scientists also mentored students engaged in five different curriculum modules, which were categorized on the basis of the subject of inquiry. Most of the scientists were new to the *PlantingScience* project. However, some scientists had mentored students groups and voluntarily returned to the project several times. Table 1 reports numbers and percentages of the occupations and subjects of inquiry in which the participating scientists were engaged.

Table 1

Scientists' Occupations and Subjects of Study

		N	Percentage
Scientists' Occupation	University affiliated	12	33
	Non-university affiliated	7	20
	Graduate students	17	47
Subject of study	The Wonder of Seeds	18	50
	The Power of Sunlight	5	14
	Foundations of Genetics	7	20
	C-Ferns in the Open	5	14
	Celery Challenge	1	2

Data Analysis Procedures

Data analysis procedures of the grounded theory process include data managing, reading and memoing, describing, classifying, interpreting and representing (Creswell, 2007). Printed dialogues were coded by using open, axial, and selective coding strategies as stated by Strauss and Corbin (1998).

In the open coding phase I examined the written student-scientist dialogues and used a constant comparative approach until each category was saturated, in other words until new information does not provide insight into the category as Creswell (2007) mentioned. These categories were composed of properties, i.e., the conceptual aspects of a category whereas a category is a conceptual element of a theory. At the beginning of my coding, many constellations existed to permit the formation of categories out of properties. Then, a central category that was extensively discussed by participants was selected as the central phenomenon of the study. By using the same comparative approach, the data were reviewed and compared with the central phenomenon. Once open coding was completed, initial categories were created, color coded, and listed.

In the axial coding phase, the data were reviewed and the categories were compared to relate and explain the central phenomenon. Compared to the previous phases, axial coding aimed to elaborate the paradigm by building relationships between conditions, actions and interactions, and consequences (Corbin & Strauss, 2008). As I analyzed the data, each category was associated with a specific memo or developing diagram. According to Corbin and Strauss (2008), "They [memos and diagrams] are working and living documents. When an analyst actually sits down to write a memo or do a diagram, a certain degree of analysis occurs" (p. 117). After engaging in axial and selective coding for the central phenomenon, my analysis yielded substantive theories and a general formal theory at the end. Finally, I created a visual model and expressed a theory to present the relationships among concepts and the story behind the research questions.

Strategies for Validating the Findings

By nature, objectivity of the findings in qualitative research is evaluated differently, unlike the results of the quantitative research. Corbin and Strauss (2008) suggested the term "sensitivity" to mean "having insight, being turned into, being able to pick up on relevant issues, events, and happening in data" (p.32). Sensitivity is used instead of objectivity to explain the validity of the explanations in grounded research. In addition, Glaser and Strauss (1999) mentioned, "The criteria [for validity] may appear flexible (too much so for validity, one critic has said), but the reader must remember that our main purpose is to generate theory, not to establish verification with the 'fact'" (p.48). However, in later years the validation strategies have been highly discussed among scholars studying qualitative research. Several different perspectives exist regarding the validity of a qualitative study. Approaches can change as different philosophical lenses are applied to the methodologies employed.

In this research, I adopted Creswell's (2007) eight validation strategies for qualitative research. These strategies are primarily based on Lincoln and Guba's (1985) qualitative validity standards of "credibility," "transferability," "dependability," and "conformability." They are, respectively: "prolonged engagement and persistent observation in the field," "triangulation," "using peer review or debriefing," "negative case analysis," "clarifying researcher bias," "in member check," "rich thick description," and "external audits" (Creswell, 2007).

Basically, my prolonged engagement with the project and related research spanning over three years allowed me to build trust, learn the culture, and check for misinformation in the data I collected. I used previous publications and reports that had come out of the project for theoretical triangulation as a means to corroborate evidence from different sources. I also shared and discussed my findings with the committee members throughout the process. To minimize researcher bias, I provided detailed explanations and was clear about my position. In member checking, I discussed the theory and the connected relations among concepts with a scientist who participated in the project as a mentor to confirm the credibility of the findings. I provided thick descriptions that can allow readers to make decision about the transferability of findings. I also used an external audit that has no connection to the project and the study to examine if findings, interpretation, and conclusions are supported by data, following the suggestions of Lincoln and Guba (1985).

Results

Initial Phases of Inquiry: Hypothesis and Research Question and Design of Experiment

Two types of factors affected the nature of inquiry and the nature of dialogues between students and scientists. These factors leading the inquiry process were (a) *hypothesis and research question*, and (b) *design of experiment*.

The hypothesis and research question category was the driving force of the connection between scientists and students, and indirectly the entire scientific inquiry, because it constituted the foundations of both the mentorship relation and the process of scientific inquiry. The hypothesis and research question category consisted of six sub categories obtained through the data analysis. These were: (1) *requirement of a prediction and a research question before starting the investigation*, (2) *focusing on the role of the hypothesis* (i.e., every experiment has a purpose behind it), (3) *importance of alignment between methods, experimental design, and research question*, and (4) *defining hypothesis and prediction as educated and reasonable guesses*.

Commonly, the dialogue between scientists and students began with a discussion about the research question. Some scientists preferred talking about themselves and their research first, but oftentimes the dialogue began with the research question. Two main reasons existed for establishing the priority of the research question talk. First, even though *PlantingScience* project aimed to give students opportunities to carry out an experiment towards their interests, the quest for a research question was somehow extrinsic. In other words, the research question was mandated by the teacher as a requirement or asked by the scientist mentor. Second, scientists explicitly indicated the importance of having a research question at the beginning of the investigation.

This first sub-category, requirement of a research question, consistently appeared at the very beginning of the dialogues between scientists and students. It was obvious from the data that the scientists followed an order as they begin their projects with their assigned student groups. Scientists explicitly and repetitively remarked, "Start by forming a testable hypothesis…," and "What is your research question?" as first comments after introducing themselves and saying hello. Scientists also believed that every experiment must have a purpose behind it and talked about the role of hypothesis in scientific research.

The other sub-category, role of the hypothesis, emerged as a separate category. Scientists talked about the role of hypothesis and tried to convince students that hypothesis has a role in scientific inquiry and it is more than a randomly selected question. A scientist, for instance, specifically stated, "I [She] find that formally making the statement is useful as it allows you to clearly see what you need to do and formalize your expectations."

Scientists often expressed the importance of the alignment between research question and research components such as prediction, experimental design and equipment students have in the classroom. They explained this relationship clearly as follow:

> Your experiment sounds really interesting! So you have a good research question, but not really a hypothesis. Now what you want to do is think about your expectations. Basically create your hypothesis by re-framing the question in a different way that includes your expectations. You want to give a try?

Another scientists said, “Your new hypothesis is exactly what it should be – a clear statement that includes the treatment and species information as well as predictions.” Scientists also distinguished hypothesis and prediction from a simple research idea and explained it as an educated or reasonable guess. Here is an excerpt from a dialogue:

“Now, the next fun step will be to think about your research predictions. This means that you will become more specific about your expectations. Think about making an intelligent guess called hypothesis.”

Most of the time scientists used the terms ”educated” and ”reasonable” to define what a hypothesis is and how in practice it is different from a research idea. These statements were recognizable examples from investigated dialogues. While we would not expect to see these statements from a teacher in a traditional science classroom, statements such as these were naturally occurring throughout the dialogues supporting students’ scientific inquiry process.

The second factor leading the direction of the inquiry between students and scientists and the nature of the dialogues was identified as design of the experiment. In addition to the discussions regarding research questions between scientists and students, dialogues about experimental design were a determinant affecting flow of the investigations by establishing the stage for future dialogues. I assigned three sub-categories to the design of the experiment category: (a) *controlled experiment*, (b) *revision of the design*, and (c) *working on one variable at a time to incorporate variables and procedures*. The sub-category controlled experiment was the dominating factor to student-scientist dialogues as they discussed the experimental design of the inquiry. Scientists mostly talked about controlled conditions, their importance, and why students should always have a standard or a control group in the design of their experiments. Scientists assisted students to design their experiments in controlled settings by asking questions as seen in the following excerpt: “Can you guys think more specific about what things would be controlled in your experiment? How will you control it, and what variables will be controlled?” As seen in the example, unlike traditional classroom science, the scientists did not discuss experimental design as a cooking recipe for following procedures. The second sub-category was revision of the design. Scientists explicitly stated that changes can be made on design when needed in response to students’ comments that they believed that a design “cleared” by the teacher could not be changed; it was too late to make changes on it. Scientists also encouraged students to keep alert on points regarding design needs to be changed. This kind of dialogue provided flexibility to groups struggling with design limitations. The last sub-category for the design of experiment represented scientists’ emphasis on changing one variable at a time to incorporate variables and procedures. Many student teams had a tendency to change multiple variables at one time and implement all of the changes to their designs. In such cases, scientists stressed the appropriate methods for incorporating variables and procedures. For example, the scientists said:

> Keep in mind that when you are designing the experiment make sure that there is only one variable that you are changing. This means make sure that the plants all receive the exact same treatment except for one thing as the variable you are testing.

People might expect that the initial phase of the inquiry should only include the initial step, identifying a research question and hypothesis, of scientific inquiry. However, data in this study revealed that decisions regarding research question, hypothesis and experimental design, all together influences the further dialogues between scientists and students regarding the nature of science in other categories as well. These sub-categories constitute the backbone or the structure of the inquiry process. The quality and characteristics of the dialogues did not always necessarily remain same. That is to say, sometimes major and minor revisions asked by mentor scientists could affect the following steps, but initial phases of inquiry was still where the scientific inquiry experience was structured as a result of the collaboration between scientists and students.

Phenomenon: Dialogues Under Nature of Science Umbrella

Once the initial phase of inquiry driven by the leading research question and design has been agreed on, the role of the mentor had started to get its shape around a core phenomenon called “nature of science dialogues.” Existing and emergent codes and categories were compared and contrasted with this central category; the category was refined and the results produced had many connections to other main categories already discussed and will be discussed in the following sections. The category labeled as *nature of science dialogues* resulted in seven sub-categories: (a) *interest driven science,* (b) *creativity and curiosity*, (c) *collaboration in science*, (d) *purpose of science*, (e) *science as a human activity,* (f) *failure as part of research,* (g) *revisable science*.

Scientists had a major role to discuss nature and features of science with students under the theorized categories. For instance the first sub-category *interest driven science* understanding was formed based on the scientists' explanations regarding what science is. When scientists introduced themselves and explained their motivation to become a scientist, they described science as "interesting," "exciting," "fun," and even "crazy." Also, scientists expected students to pick up a research question that was interesting for them. They supported this discussion by saying that science has a purpose and it is interest driven. One scientist, for instance, said he found science fascinating: "I am actually interested in all plants. Once you begin to learn about plants, there are fascinating aspects to all of them." Whether this kind of dialogue statistically increased students' interest in science or not is something we cannot conclude from these examples. It is clear to me as a researcher, however, that hearing from a scientist that he or she loves doing science with plants is an authentic experience coming directly from a scientist, a type of experience that students cannot have in a traditionally formal school setting.

One other sub-category, curiosity and creativity, was explained by scientists as a characteristic of science. For instance, a scientist said, “You will probably soon find that experiments are not all about collecting and analyzing data, but also require a lot of creativity and planning;” another said, “I want us to brainstorm ideas together and express our curiosity to explore more about Plants and Science.”

Scientists also expressed their understanding of science in a way that science is a collaborative entity and science is a community job. For example, one scientist commented and said that “That’s the first part of working together to do science (we call this “collaboration”). The tricky part of collaborating with your peers is to take that broad list of ideas, and narrow it down to a specific question/experiment.”

In addition, scientists mentioned that sharing findings and presenting results at conferences is part of what is called science and that they liked to do so. For example, “This is how scientists present their work in conferences – to tell others about the cool stuff they do! Making presentation is one of the fun parts of doing science, so I hope you have fun too!”

Scientists also assisted students in checking other groups’ online work to see what others had done in a specific situation or to learn what kind of research questions other students had generated. Basically, scientists conceptualized science as a community act and made connections with students’ efforts to become a team and emphasizing teamwork as important. Also, scientists reflected the interdisciplinary characteristics of science by identifying connections with other fields of science.

One other sub-category emerged under the nature of science, which is the core phenomenon in our study -- the purpose of science. Scientists’ statements ranged from benefits of science to the contribution of science as being a contribution to scientific knowledge. Scientists thought and often expressed that science or scientific investigation has a purpose behind it. There were explicit statements about the purpose of the science. Although it is open to discussion, the scientists in our sample used sentences stating that the purpose of science was to identify things, to be useful, or to improve our scientific knowledge. For example a scientist said, “As you may have learned in class, every experiment needs to have a purpose behind it, in order to show what you’re interested in learning about.” In this comment, for example, the scientist expressed that science produces useful and valid information and “one purpose of the inquiry is improving our scientific techniques and knowledge.”

According to the scientists included in the analysis, science is not an individual action and there are some mechanism including peer review and checking other sources to obtain and confirm data. The sub-category, science: a human activity, emerged as a constellation spread over the dialogues analyzed. In other words, instead of having strong single excerpts from the conversations, I observed that scientists tended to use science, technology, and society connections in providing students with historical examples and to connect their research areas to their daily lives. Both of these strategies made students’ conceptual science understanding more concrete. In addition, although scientists tried to use very informal language to communicate with students and to break the ice with them, as they progressed through inquiry they insisted on using more scientific language. As an outcome, more scientific terms and more attention to the use of them occurred at the end of the students’ inquiry experience. These findings represented science as a human product developed through idea sharing via a language specific to it.

Failure as a part of the research process emerged as an interesting and highly repeated category in scientists' comments. As students were mostly dealing with and focusing on original research questions with unknown results (which is totally opposite of the school-based inquiries in which students are investigating questions that already have an answer), having an unpredicted result had a shocking effect on most groups. Students called their results a "failure." For this reason, I named this sub-category as *failure* on purpose to reflect the feelings and struggles that students experienced when their experiments did not turn out as expected. In this sense, scientists had important roles in explaining to students the nature of error and failure in scientific investigation. Scientists used examples and explanations to try to convince their students that failure was an important part of the process. For example: "That type of thing [failure] happens in science; sometimes experiments encounter problems," "Never worry—it's almost certain that things won't go the way we expected when we're doing science," "Don't worry about being confused – this is normal part of the scientific process."

Students always considered their errors as failures as they made conclusions about their scientific investigations. As a result, making a mistake was a traumatic event for students in *PlantingScience*. Other comments in this category included scientists' attempts to convince students that obtaining different results from their predictions was a normal thing. Despite these supportive statements, however, if something went wrong in the experiment, students just intended to stop doing it and complained about the mistake they made.

The last sub-category is revisable science. The conversations abut reflecting and making revisions on results and experiment is another theme that was commonly seen inside the dialogues. In the *PlantingScience* groups studied, the scientists gave great emphases on revision of the inquiry components, including research question, experimental design, and procedures. However, students had difficulty in understanding and interpreting the revisability of the scientific information and process. These difficulties were most probably due to the linear view of science presented in traditional science classes. Making revisions as a coping mechanism was also applied by scientists to support student groups who thought they failed when something went wrong as they experimented in the classroom. Revision appeared as a part of the process that was applied to different levels of inquiry. Also, revision was seen in recommendations of the approach to minimize the error. Even without having unpredicted results, students did not know what to do next and got panicked at the end of their investigations. For instance, a scientist told students that they should look at the same thing from different perspectives at a time when they could not proceed anymore. When students struggle, they might perceive that science is a linear process and not understand that revisability is part of the scientific process. In such instances, scientists made suggestions and said, "Part of research is going back to the drawing board when things don't go the way we had planned."

To sum, the dialogues under the nature of science umbrella were identified as the core phenomenon that interacts with other components of the model proposed in this study. Also, the dialogues regarding the nature of science were highly varied due to dependencies on the content and intervening conditions.

Strategies: Social Function of Scientist-Mentor

In this section, the strategies that scientist mentors took on are discussed from the perspective of social functions they offered as mentors. *PlantingScience* can be identified as a social environment where its members (in our case they are students, scientist, teachers, and project coordinators) interact with each other by using the norms of a specific culture created for the project. In this sense, scientists' social function has emerged as an important category to explain the process of student-scientist partnership in *PlantingScience*. Scientists used social strategies to enhance students' authentic science experiences and to cope with groups and individual students who were struggling as they progressed through inquiry cycle. The following descriptions of these strategies help us explain each function in detailed.

The category labeled as *social function of scientist-mentor* resulted in six sub-categories: (1) *questioning* (asking Socratic and prompting questions), (2) *getting to know* (trying to learn the settings inside the classroom), (3) *checking* (checking research components such as research question, design, knowledge, and etc.), (4) *reflecting* (reflecting on process, results, etc.), (5) *providing* (providing procedural or factual knowledge), and (6) *building* (building the concept of a scientist).

In the presence of the context and intervening conditions described above, the core phenomenon, nature of science dialogues, led to the development of strategies named as social function of scientist-mentor and its corresponding sub-categories.

Questioning (asking Socratic and prompting questions) was the first category representing the strategy used by the scientists as they mentored their student teams. Scientists, with a small exception, did not act as direct knowledge sources and instead used asking questions as a strategy to encourage students to find the right answers themselves. Scientists noted that students were starving for answers at the very beginning of the inquiry and asked a series of questions to their scientist mentors to learn more and progress through their projects. Mentors chose one of two options: either give the right answer and perform the role as a knowledge source or help students find the correct answer from what they already know. Scientists used mostly Socratic questions (rather than yes-no questions) that made students find and/or come up with their own questions. This strategy had two major implications; first, it helped students who hesitated to be part of the dialogues at earlier stages of their project. Second, students adapted themselves to this strategy and responded to questions seriously by using scientific terms and a language that they could communicate with a real scientist. Some scientists used prompting questions and asked questions that created more questions and led to new questions. Both strategies were common in the dialogues and appeared as a main approach. Typical *PlantingScience* student teams were composed of four students and one scientist mentor per team. In a classroom environment where more than 20 students listen to their teacher at the same time, we normally could not expect the teacher to pay attention to students' individual questions with the purpose of promoting more questions like a mentor does in *PlantingScience*.

The strategy, questioning, also helped students to develop the discussion section of experiments summary by partially or completely implementing these discussions to their research summary. The following examples regarding the category were obtained from scientist dialogues.

Examples:

"Why do you think there was no significant difference in leaf are between the high and low fertilizers?"

"I am asking too many questions! You see, one of my favorite mentors used to say: 'He who afraid to ask questions is afraid of learning'."

"What makes you think that a large surface area will result in a higher rate of photosynthesis? (Hint: What pigment is involved in photosynthesis and what does leaf size have to do with it?)"

Mentoring and online mentoring were two new experiences for most of the scientists involved in the project, except for the few scientists who had volunteered for previous *PlantingScience s*essions. The category "getting to know" emerged in the analysis, based on scientists' needs to get to know classroom settings, what students already knew about the subject studied, and how students carried out typical experiments inside the classroom. Scientists wanted to know what level of knowledge students possessed and whether they had had previous experiences in doing authentic experiments. In most of the cases, the initial phases of the students' inquiry allowed scientists and students to get to know each other. In this phase, the discussion included students as well. For instance, students asked questions to learn what they could get from scientists as they progressed through the experiment to complete project objectives. The following are excerpts regarding this category:

- Scientist trying to learn the things discussed in class: “Can you share with me some of the things have discussed in class?”
- Scientist trying to get information about the duration of the experiment that students carried out in class: “How much longer will your experiment go for?”
- Scientist seeking information about the lesson plan: “Can you fill me in on what is going on in your class this week?”
- Scientist getting information about the materials that students have in the lab” “What kind of seeds are you using?”

Our analysis revealed one naturally occurring limitation that online mentoring brings to a large-scale partnership project: the physical non-presence of a mentor in classroom. The analysis also revealed, however, that the issue can be minimized or resolved through the use of different social strategies, such as asking questions, uploading data, requesting detailed information from student teams, and being specific as scientists and students engage in conversations about the procedures. Thus, justification of this category as a weakness or just as a natural finding should be left to the reader rather than from my perspective as the investigator of this study.

Checking student teams’ research question, design, knowledge, and other aspects of the inquiry is the third strategy of scientists. Checking was accomplished by receiving a continuous data flow and feedback from students. A difference exists in this category from the questioning category. In the questioning category, the purpose of the questions that mentors directed were to make students think and find an answer at a moment in scientific inquiry process. However, in checking, the purposes are to supply information to scientist mentors from student groups and to keep students active in the scientific process. Examples include the following:

- A scientist following checking if students need help, “If you need any advice with the report, just let me know. I’ll keep checking in for the next several days.”
- A scientist requesting products, “Yes, as soon as you put together some graphs, let me know. I’ll be at a meeting Wednesday through Friday this week, but I’ll try to check in and give you some feedback, so that you’ll know if they are easy to read, understandable, etc.”
- A scientist checking student team’s project idea, “How are you all? Have you been thinking about your research idea?”
- A scientist checking students’ knowledge, “Can you give two examples of experimental design that you know?”
- A scientist checking research results, “How long are your plants growing for? The plants you mated together, do you see seeds developing?”

As seen from these examples, this category serves orchestration of the inquiry by targeting different phases of it. I defined checking as a social role due to this characteristic.

Another strategy that scientist mentors commonly used was reflecting on. This category refers to a strategy in which scientists provide reflection to students’ inquiry experiences as they progress through it. Especially the scientists who wanted their students to lead the scientific inquiry had used this strategy to provide feedback and make students progress to the next step. Since as mentioned in the previous categories scientists avoided providing direct information and serving as a transmitter, instead they used strategies to direct students to the right answers. Unlike checking category the direction or flow of the information this time was from scientist to students. It mainly functioned as an antagonist feedback mechanism; checking students' progress first and reflection on it next. As you can expect from the function of this mechanism, it increased student engagement and participation in online dialogues. The groups who did not have these two categories did not contribute to dialogues well.

An example from dialogues for reflecting category:

> Any thoughts on how you can use the information you've learned from your experiment for a real life application? You have concluded that bleach is not good for plants, so can you make any recommendations about bleach in the environment, for instance?

One other function of this specific strategy was to encourage students to reflect on their own experiment and talk about the research findings. For instance, questions like "What would you have changed if you were asked to do this whole experiment all over again?" and "Why do you think that there was no significant difference in leaf area between the high and low fertilizer?" aimed to encourage student to participate productively in a discussion about their own claims.

In addition to all these strategies mentioned above, scientists provided (providing strategy) procedural and content knowledge for students to do the inquiry in the

PlantingScience project. Scientists explained scientific processes and mechanisms occurring in nature. For instance, they used metaphors to simplify the mechanisms occurring in nature and by making real life connections to make abstract concepts more concrete.

Examples:

> For example, if we knew nothing about cars, but were studying them, we would find one that didn't drive correctly – maybe one that never stopped. To figure out why it wasn't driving right, we could carefully investigate each of its components –engine, tires, breaks,…to see which wasn't the 'wild type' by comparing it bit by bit to a car that does work.
>
> As you probably have figured out, you don't need soil for seeds to germinate. However, once the seedling gets big enough and starts making its own energy through photosynthesis, all of the nutrients that plant will need will be taken up by the roots.

The final strategy, which also can be named as a function, is building by giving examples in the form of "a scientist would do…" or from their own research. Scientists mostly used this strategy to create the concept of a scientist in students' mind; my analyses revealed that students found difficulty in conceptualizing what their mentor scientists were like and that mentoring scientists found difficulty in telling their students what being a scientist was like. For example, scientists said "When you think of a scientist, what do you think is that we do everyday?," "Most botanists will analyze plants to some degree, depends on what they are studying.," "Most scientists doing something like this (and we do!) would phrase it this way.," "Most scientists will refer to as a control group." As seen in these examples, in addition to direct and explicit statements, the concept of a scientist sometimes was integrated into procedural and process related dialogues.

Context in Which Nature of Science Dialogues Developed

Nature of science related dialogues were developed in response to the initial phases of inquiry including picking up a research question and making a decision about the design. These dialogues were highly influenced by particular contextual indicators, which were inherent to decisions regarding the hypothesis and research design. I classified these contextual indicators into two categories: (1) *nature of investigation* and (2) *data gathering*. The nature of investigation category included: (a) *methodology of inquiry*, (b) *elements of investigation*, and (c) *experimental objectivity*. Unlike the core category nature of science dialogues, this category focused on features of investigation specific to the inquiry upon which the students were working. The dialogues were constructed within the context of nature of investigation.

The first sub-category was methodology of inquiry. Essential concepts used in plant related projects hosted on the *PlantingScience* platform that were explained by scientists were *causality*, *comparison*, *testing*, *analysis* and *synthesis.* Scientists often and explicitly used terms "cause", "effect", and "causality" when they engaged in dialogues with students while making decisions and working on the research question. Scientists also evaluated experiment results in causality context. The second method frequently mentioned by scientists was comparison, such as comparing results from experimental group with control group. At a minimum level, scientist used testing, analysis and synthesis terms to they obtain scientific information. However, they mostly expressed a uni-dimensional understanding in terms of methodology of science and did not offer students or involved other approaches as alternatives in their dialogues. Sometimes they proposed a multi-dimensional understanding in terms of methodology of science, but it was rare. For instance a scientist explained scientific inquiry and said:

> "So, where do we start? It all starts with deciding what you are interested in: do you want to:
>
> → measure something (how long, how big, how wide, how many)
>
> →describe something (if__than_, this compared to that)
>
> →investigate a process (what if, how does, can we)
>
> →break it and fix it (why does it, how does it)"

Elements of inquiry was the second sub-category representing the nature of investigation in plant science. Scientists used *thorough* descriptions and conclusions, predictions, methodology, a non-linear design, brainstorming and randomness as elements of inquiry. They stated that science requires "descriptive and thorough conclusions," "any well design requires a research methodology," and etc. The dialogues were developed within the context of these elements. And finally, scientists emphasized the importance of *experimental objectivity* through discussions about reliability of scientific knowledge and experimental reproducibility. Scientists for instance suggested students that taking detailed notes and research journal was important to make other people to carry out the same experiment and obtain same results. For example:

> These are just few questions I can think of that someone who may want to replicate your experiment might ask. Remember, one of the components of the scientific method (and therefore scientific research) is experimental reproducibility. Designing an experiment that others can replicate is one part of making it scientifically sound – and can also be extremely useful, especially when someone has question similar to the ones you have!

The second suggestion that scientists often made for students to enhance objectivity of research findings was quantifying the qualitative measures and results to communicate with others based on standardized measures. For example, scientists said "Did you figure out a good system for quantifying plant health?," "I would also recommend measuring the seedlings with a ruler to estimate the differences between your groups in a quantitative way," and "Make sure that you add these QUANTITATIVE (in other words number based) measures into your experimental design." This finding also specified that scientists in our sample thought that plant science was quantitative in nature.

On the other hand, the category data gathering included (a) *keeping record of things*, (b) *measurement*, (c) *reliability*, (d) *operational definitions*, (e) *data representation*, (d) *naming variables* (dependent and independent).

Scientists repeatedly talked about the importance of record keeping in scientific inquiry and explained it to students in online *PlantingScience* platform. Scientists wanted student to keep detailed records of supplies, materials used, and procedures. They stated that record keeping is important for a successful research project and asked them to always record their data. Scientists also explained that data collection could be important for someone who would like to replicate students' experiment. Examples for record keeping sub-category:

" The important thing is to always record what you did."

"That was definitely a good thing to write down, remember it is important write as much as you can think of (errors, mishaps or observations) because the more you write the easier it will be to look back at the experiment."

Another data gathering related sub-category was measurement. This sub-category was characterized by the discussions regarding measurement and measurable variables. Scientists emphasized that all variables should be measurable and they also expected students to use measurement as objective evidence to support research prediction and question. Scientists also wanted students to use standards such as a ruler to make them quantify their measurements rather than using only qualitative examples. In addition, they wanted students to have more and accurate information to get more reliable results. For example, a scientist said, "Sometimes having more measurements can give you a clearer picture of how your plant is responding to treatment."

The dialogues regarding measurement oftentimes led to discussions about reliability of data. Reliability of scientific information has been discussed around the importance of repetition and replication in plant science. Also, scientist wanted students to record every detail as much as they could do. In this sense, the discussion regarding replicates and its importance in science has been discussed many times. There are some excerpts regarding reliability category from the dialogues:

“This is why having replicates is such a great idea!”

“Replication is a good thing to have in your experiment!”

“Figure out how many investigations [replicates] you will need before you are convinced that your hypothesis is correct / incorrect.”

“It is always important to be honest with your results and say exactly what happened during the experiment so that you don’t end up making up data.”

The analysis revealed that scientists appeared to have difficulties in mentoring student teams when it came to students’ paying attention to the operational definitions of the terms in *PlantingScience*. As a clear observation, scientists oftentimes requested operational definitions of the terms. Apparently, sometimes the reason for the request was to facilitate the scientist’s understanding of what the students were attempting to say or to teach students to pay attention in their use of the same scientific language with their mentors and with their group mates. The request for operational definitions was understandable and reasonable, because students often use words like “better,” “healthy,” “more,” and “normal” in their hypotheseis to represent a variable under investigation.

Other examples:

“What does it mean to behave? How do plants do it, just other living things?”

“How will you measure “growth and health”?”

The last sub-category emerged as a result of constant comparison analysis regarding data gathering was *data representation*. During data collection and towards the end of the scientific inquiry investigation, scientists assisted and recommended that students represent the data using graphs, labels, scale, or numbers. They also suggested that students keep research journals to include more details about their research. Scientists mostly asked students to update them by posting data tables and graphs and even sharing images of the plants in the classroom.

Intervening Conditions Influencing Dialogues between Student and Scientist

In addition to context, there are also intervening conditions, influenced the core category and other categories as well. These two categories were: (1) *scientists' occupation*, and (2) *subject of the study*. Intervening conditions were not included in the contextual category, because these two categories mentioned here are independent from the context.

Occupation. More than 900 scientists are currently involved as scientist-mentors in the *PlantingScience* project. These include university professors, graduate students in biology related departments, scientists from industry, scientists from non-governmental and government organization volunteered to mentor. The purpose of this analysis was to understand if a demographic variable, such as occupation, appeared to correspond to scientists' understanding of science as they mentor student teams. Although the occupation or the scientists' job definition varied, I categorized them in three groups: (a) university affiliated, (b) graduate students, and (c) non-university affiliated (e.g., industry, governmental and non-governmental institutions). Based on the comparison of these three groups with each other and with previously analyzed groups I observed differences among these three occupations in terms of the way the scientist mentor expressed it. For this specific analysis I compared 5 groups whose scientists are university affiliated, 6 groups whose scientists are graduate students, and 6 groups whose scientists are non-university affiliated. To make a fair comparison I kept group numbers almost equal.

Table 2 shows the presence of categories in groups classified based on scientists' occupation. As seen from the table, the groups did not mention each category equally. The purpose of giving this table was to show how each category was distributed among occupation groups, so the frequency comparisons could make more sense. Table 3, on the other hand, presents the frequency counts of the codes for each category within groups they were present. When three groups compared by frequencies of five main categories (NOS, social role, experimental design, nature of scientific investigation, hypothesis and research question, and data gathering), graduate students contributed more to the nature of science talks whereas non-university affiliated scientists contributed least to this category. However, graduate students contributed less to the social function category. Interestingly, we did not see any other category that is significantly different than the other categories. Thus, scientists' talk regarding other three categories did not show meaningful difference. In the following sections each occupation type was described in detailed.

Table 2

Number of Groups Included Understanding of Science Categories as Grouped by Occupation

Category	University Affiliated n=5	Graduate Student n=6	Non-university Affiliated n=6
NOS	3	5	2
Social Role	5	4	5
Experimental Design	3	2	3
Nature of Scientific Investigation	2	4	5
Hypothesis and Research Question	2	4	3
Data Gathering	3	5	5

Table 3

Frequency Counts Corresponding to Six Main Categories of Understanding of Science

Comments by Aspect of Science			Comments by Occupational Type					
			University-Affiliated		Graduate Student		Non-University Affiliated	
Aspect	Number (n)	Percent (%)	Number (n)	Percent (%)	Number (n)	Percent (%)	Number (n)	Percent (%)
Social Role	56	26	20	31	17	21	19	29
Data Gathering	51	24	13	20	21	26	17	26
Nature of Science	29	14	13	20	15	19	1	1
Experimental Design	29	14	12	18	8	10	9	14
Nature of Scientific Investigation	25	12	4	6	11	14	10	15
Hypothesis and Research Question	21	10	3	5	8	10	10	15
Total	211	100	65	100	80	100	66	100

University affiliated scientists

NOS. Scientists who were affiliated with a university mostly told students what science is all about and explained science as an interest driven thing. Then, at a lower level, they talked about the role of creativity and collaboration in science, and explained science as a process.

Social role. In this category, university affiliated scientists mostly used Socratic questioning and reflected on students' inquiry projects. They also used metaphors and examples from their own research to connect science to real life events. At a minimal level, they tried to learn the settings inside classroom and checked students' knowledge and research questions. They provided procedural knowledge to students.

Experimental design. University affiliated scientists mostly and highly emphasized the role of controlled experiments and the importance of having equal setting in both control and experimental groups. At a minimum level, they talked about testing one variable at a time to incorporate variables and procedures.

Nature of scientific investigation. At a minimal level, they talked about methodology of inquiry, elements of investigation, experimental replicability, and quantifying qualitative findings.

Hypothesis and research question. They contributed at a minimal level talk about research question and focused on hypothesis.

Data gathering. University affiliated scientists mostly talked about measurement and measurable variables and equally talked about reliability and repetition and a little bit about data representation. A new category, dependent independent variable difference, also emerged based on the results. However, university affiliated scientists gave less emphasis to this category in comparison to other groups.

Graduate students

NOS. Graduate students mostly talked about what science is. Secondly, they explained science as a process and as a human endeavor by using historical examples and scientific information. At a minimal level, they talked about collaborative and creativity parts of science.

Social role. Graduate students mostly used Socratic and prompting questions as they engaged in dialogues with students. At the same level, they tried to learn what students were doing in the classroom. Equally, they used the checking strategy to control students' progress. In addition, they explained scientific procedures such as root formation and photosynthesis to students the connection between real life and science.

Experimental design. This category was graduate students' weakest point compared to the other groups and within the group. They often talked about the impotence of controlled experiment, focused on experimental design, and at a minimal level stated the possibility of revisions in design.

Data gathering. This is their strongest category among other main categories. Mostly, they talked about record keeping, measurement, measurable variables, and reliability of data. In addition, they talked slightly about operational definition of the terms that students used.

*Hypothesis and research question**.*** For student mentors this category was relatively weak. They talked a little bit about hypothesis and alignment between research components. However, they talked more about revisions made on research question or predictions.

Nature of scientific investigation. Graduate students mostly talked about methodology of investigation. At a medium level they talked about the elements of investigation and quantifying qualitative results for the objectivity of research. They mentioned brainstorming as way of creating new ideas. This finding is unique to this group.

Non-University affiliated scientists

NOS. The weakest point of non-university affiliated scientists was the nature of science category. There is almost one example, a small dialog about the characteristics of science, from more than six exemplar groups included in comparison.

Social role. They mostly used Socratic questions in their dialogues. Next, they provided reflections related to the scientific inquiry and made connections between real life cases and science. They used strategies such as checking and providing procedural knowledge to students at a minimal level.

Hypothesis and research question. In this category, non-university affiliated scientists mostly talked about the order of prediction, hypothesis, and research question. This finding somehow represented a linear understanding of science. Also, at minimal level, they talked about the importance of prediction and hypothesis, purpose of the experiment, and alignment among all these research components.

Data gathering. The second strongest category for this mentor group was data gathering. They spend most of their time in talking about measurement and data representations. Secondly, they suggested students to keep record of things they did during investigation. At a minimal level, they emphasized the importance of reliability and asked for operational definitions of the terms students used.

Experimental design. Non-affiliated scientists only talked about controlled experiment and focused on the importance of design. The variability within this category was minimum.

Nature of scientific investigation. Non-university affiliated scientists paid attention to the methodology of investigation such as talking about cause effect relationship. They also included the elements of inquiry and discussed objectivity through replicability and quantified measures. However, the discussion was at minimal level.

Subject of study. Subject of study was the second of the intervening conditions investigated in this research. To be able to answer research question regarding the association of subject with how scientists represented their understanding of science, five *PlantingScience* modules were compared with each other to see the variability among subjects. Among those five, two modules exhibited distinctive characteristics. Due to the similarities of the photosynthesis module in scientists' understanding of science and the difference of the genetics module with other modules, these two modules were included in the analysis to represent a group with extremes and a group with communalities with the rest.

Plant genetics. Based on our comparison, the genetics module appeared to be the most different module in terms of scientists' talks about main research categories. The scientists mentoring genetics groups mostly used statistics and numbers in their dialogues. They used correlation and comparison as the methods of investigation, whereas they gave less emphasis on observation based information due to the nature of genetics. The talks about revisions of procedures were limited and not frequent. They provided factual knowledge rather than process related information to the students they were mentoring. In the data analysis section, they used statistical analysis based on the data collected through high repetitions. The scientists mentoring genetics groups in our sample also did not discuss the nature of science and the procedures involved in inquiry. Based on the information above, the groups studied plant genetics were distinguishable from the other groups.

Photosynthesis. The scientists mentoring photosynthesis module engaged in experimental design and procedure related dialogues with the students. They focused more on measurement because they included many variables and corresponding treatments to these variables. The nature of investigation described and used by mentoring scientist were cause and effect unlike the genetics module. Scientists mostly used Socratic and prompting questions as a strategy in this module. They stressed the importance of record keeping and revision to fix problems when something goes wrong. Scientists also provided more reflection on results unlike the genetics module. They also talked more about revisions and process.

Outcomes of Scientist Mentored Inquiry

In *PlantingScience* project when the research comes to an end, either teacher or *PlantingScience* staff notifies students and mentors to finalize their research project.

Based on the information collected from our data sources, there were four types of research at the end. These were: (1) rich and fully complete, (2) rich but incomplete, (3) asynchronous, and (4) incomplete.

Rich and fully complete groups posted their research questions, experimental design, procedures and conclusions on the web site and had engaged in dialogues with the mentoring scientists. This outcome is expected when partnership begins with a good immersion and continues well if students are motivated and scientist mentor is posting on time. This group type posted and uploaded research data and discussed their findings with scientist mentors. They also used the platform and the opportunity of having a real scientist mentor effectively. As evidence, these groups had the longest student-scientist dialogues. The key element here is the orchestration and synchronization of both research elements and individuals (students and scientists) in the group. Especially scientists with previous mentoring experiences were good at this group category.

Rich but incomplete groups engaged in a rich dialog with their mentoring scientist throughout the project, but due to time management problems they were not able to complete the project requirements. Based on the dialogs examined there were two main reasons having this type of outcome. First, in some groups the scientist did not pay attention to the schedule and spent more time on conversations. Second, although the scientist encouraged students to finish the project requirements, team members did not pay attention to his or her warnings. Most of these groups partially completed their research summaries and did not finalize their research with a conclusion. Also, uploaded information and presentations sometimes did not exist. Again, time management, especially not having enough time and rushing towards the end of the research was an important factor in this type of outcome. The same issue had also been discussed by a group of scientist-mentors and teachers in a *PlantingScience* focus group meeting held in Ohio (Stuessy et al., 2012).

Asynchronous groups are groups that would be included either in complete and incomplete groups, because due to un-synchronization between the team and the mentor these groups did not benefit from their mentors and completed or did not complete their projects. In some groups, the scientists did not respond on time and the students already decided their research questions and experimental design. On the other hand, in some groups, the students carried out their experiment beforehand, even before initially talking to their mentors. In both cases, scientific inquiry experiences of the students did not meet the theoretical and practical requirements of online mentored inquiry project.

Unfortunately there were fully incomplete groups that could not be included in our analysis due to lack of dialogues and information present in research summaries. Since we do not know why these groups produced fully incomplete projects, we can only make some reasonable guesses. Typically in these groups, *PlantingScience* staff made the initial post and then there was no posts or only one post from a student or a scientist. The groups might quit projects due to some unknown reasons.

Overview of the Model and Propositions

From the information emerged from the data I developed the relationships among initial phases of inquiry, core phenomenon, context, intervening conditions, strategies, and outcomes.

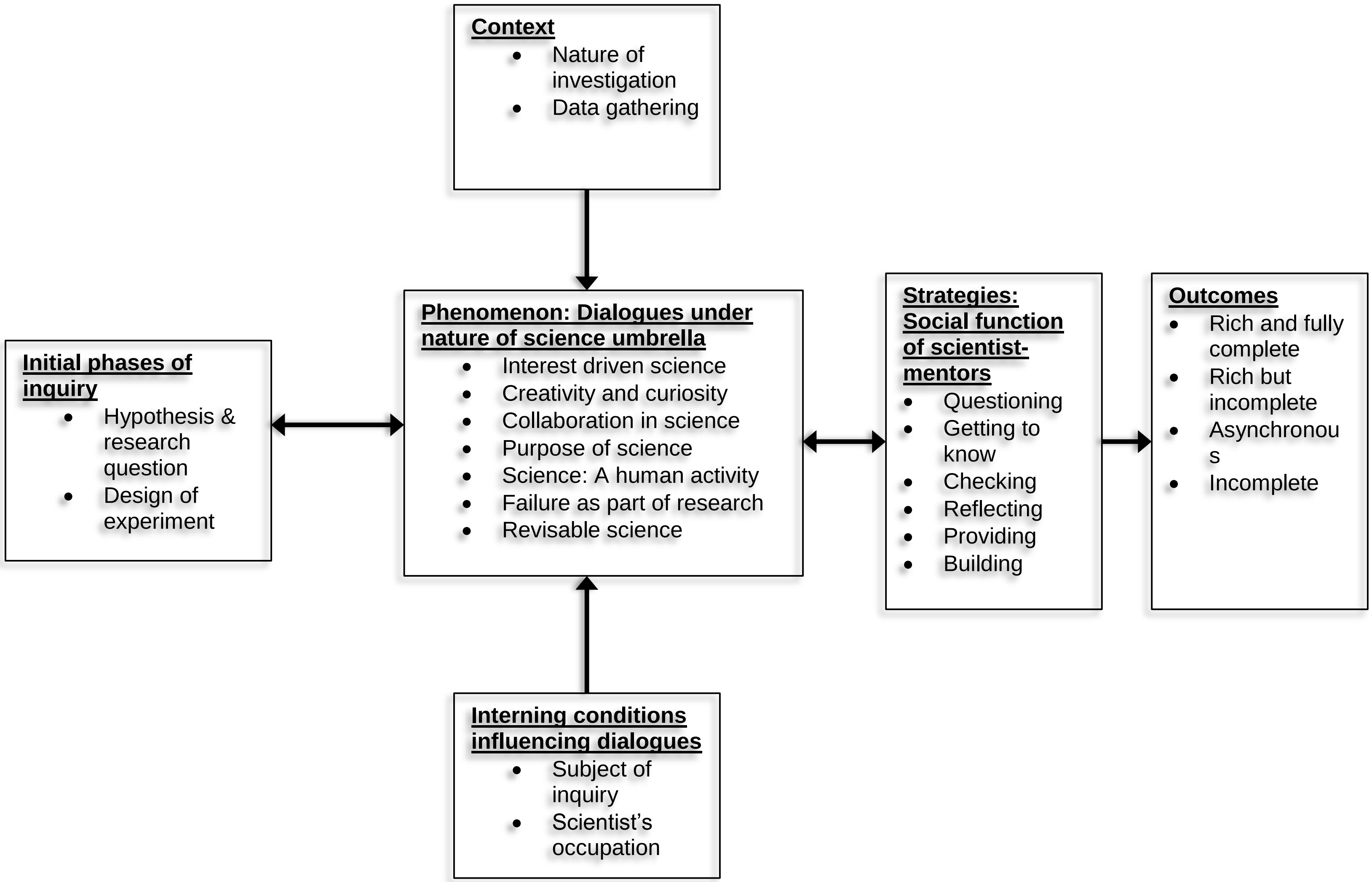

Figure 2. The model representing mentoring process in *PlantingScience* project

Logic diagrams and propositions specified these relationships (Strauss & Corbin, 1990).

As shown in Figure 2, the model suggests that initial phases of inquiry (hypothesis & research question, and design of experiment) determine the nature and quality of dialogues regarding the central phenomenon (nature of science dialogues). The central phenomenon occurs within the context of inquiry (nature of investigation and data gathering) that is inherent to scientific inquiry under development. The intervening conditions (subject of inquiry and occupation of scientists) have an influence directly on the central phenomenon and indirectly on strategies (social function of scientist-mentor) and outcomes. Thus, strategies (social function of scientist mentors) are determined by the joint effect of previous steps initial phases of inquiry, context, NOS dialogues, and intervening conditions. However, it should not be concluded that the relationships among these categories are neither linear nor uni-dimensional. That is to say, these categories including the core phenomenon or core category are like strings connected to each other in the form of a net. When one end is pulled, the shape of the net will be changed, even though the parts of the whole system will stay together. As a result, the outcome of students' scientific inquiry experience is highly dependent on the teacher's classroom orchestration of this network, which includes the following propositions.

Proposition 1. *A good beginning is important.* The initial phases of the inquiry are very important for online mentors. Almost all scientist mentors informally introduce themselves and try to draw students' attention to science and plant science. However, progress of scientific inquiry is highly influenced by a good research question and a well research design. Once scientists assist students to develop a good research aligned with research predictions and hypothesis, they easily progress to the next step in their research. However, as negative examples in our data revealed, if group has already decided the research question and the scientist mentor did not assist them to make required revisions, both students and scientist will face with problems in the future and will need to make revisions in the final stages of inquiry. This is why the alignment between research question, design and other steps is a key point in terms of flow and success of the scientific inquiry in *PlantingScience* project. Moreover, if scientists assist students to set up a controlled experiment by identifying variables and controlled settings, then students performs well in carrying out experiment and completing procedures.

Proposition 2. *Context is highly influential on enriching nature of science dialogues.* A dialog can never be constructed without a context and thus student-scientist dialogues needed to be developed around a context. In our case, characteristics of scientific investigation and features of data gathering enriched the dialogues between student and scientists about nature of science by providing material to conversations. If scientists pay more attention to the features of scientific investigation that they are using and to the details of data collection, such as repetition and record keeping, it creates more space to talk between students and scientists.

Proposition 3. *Scientists' occupations and the targeted context of study can correspond to scientists' contribution to some categories.* According to the results of the analyses in this study, different types of scientist mentor occupations show patterns in their relative strengths and weaknesses. This finding reinforces the notion that we should not assume that all scientists contribute to students' understanding of science in the same ways. Student mentors paid more attention to nature of science and less attention to procedures, whereas non-university affiliated scientists used social strategies more than other scientist mentors. Also, the targeted subject of the inquiry was found to correspond differently with the nature of science dialogues between students and scientists. In this investigation, the genetics group did not share the commonalities that other modules shared and distinguished itself as a different module among other modules in *PlantingScience*.

Proposition 4. *The richer the nature of science dialog the more social function.* Depth and richness of student scientist dialogues regarding nature and/or understanding of science characterized the role of scientist mentor as a social agent. When scientists talked more about their understandings of science and explained it to students, they directly or indirectly assumed more social roles and selected different social functions.. Also, we should make clear that this finding does not imply that the more scientist mentors talked, the more they engaged in social roles. The content and function of talk determined the characteristics of the dialog. For instance, some scientists engaged in long conversations with students but they neither served as a social element nor contributed to the students' understanding of science.

Proposition 5. *Completion of a project is not only connected to the mentor.* Although mentors appeared to have a leading role in student teams' *PlanitngScience* projects, students and even teachers could change the quality or direction of the inquiry and were therefore responsible from the outcomes. While problems like late posting and asynchronous communication may have had some correspondence to the quality of students' inquiry experiences, many other factors could also correspond to poor quality in the final inquiry product. The students' attitude towards science, scientists, the project idea, as well as the teacher's orchestration of the inquiry and comments in class, all together, could affect the quality of the *PlantingScience* project. Students' willingness to communicate with scientist-mentors and the level of autonomy they assumed could also have been determinative factors influencing whether project will end up as complete or incomplete. Thus, harmony between two parties, students-scientist, while a key in a partnership model, is not the only key. Multiple variables contribute to the quality of the *PlantingScience* learning environment and therefore could have differing impacts on the quality of students' learning outcomes. As this study focused only on the interactions between students and their mentor scientists, other studies will have to be conducted to attempt to identify the relative contributions of the many variables affecting the quality o the environment.

Proposition 6. *Scientists should not use simplistic science language with students, thus indicating an assumption that students should be treated as if they were children.* A common observation in the data revealed that scientists' use of scientific language was reflected in students' responses to their mentors. Simply stated, students responded to their assigned mentors in the same manner and intent to use similar terms and language. When scientists requested operational definitions of the terms used for research purposes, students responded to their request gradually, sometimes immediately, and started to use scientific terms and repeated narrowed definitions for the sake objectivity. Thus, scientists should avoid using simple language and assume that students are capable of communicating with them using acceptable conventions of scientific language.

Proposition 7. *Scientists should talk about themselves and their lives inside and outside the laboratory.* Scientists should begin their interactions with their assigned students introducing themselves and giving information about their life outside the laboratory (e.g., hobbies and family). Although this theme did not emerge as a single unique category in the analysis of the data, this strategy can serve two purposes. First, in the initial phases of the inquiry, these early informal conversations can create connection between scientist and students, two groups who had not been met before. Second, scientists' talk about their research and connecting it to daily life examples may change the concept of a scientist in students' minds and they may see science as a human activity. This feeling may help them choosing science as a career.

Discussion and Conclusion

Although science education literature is quite rich in terms of the research on student-scientist partnership outcomes, this study is distinctive in its systematic examination of how scientists contribute to students' understandings of science from a grounded theory perspective. I have constructed a theoretical model of scientists' contributions to students' understandings of science via online mentoring through the analysis of naturally occurring dialogues in order to ensure that the model reflects how this partnership progresses in *PlantingScience* projects. This model establishes a construct-focused framework to understand the role that scientists undertook in science education as the mentors teaching students science as an understanding.

The initial phases of inquiry, in which students are canalized towards a scientific inquiry experience, have a great importance. As Kuhn, Shaw, and Felton (1997) found in their study, engagement in discussion about the targeted topic of the inquiry enhances the quality of reasoning about that topic. The examination of student-scientist partnership in this study revealed that successful initial inquiry phases including dialogues regarding decisions about the research question and design are required and help both students and scientists have a well-developed scientific inquiry experience. Otherwise, problems inherited from poorly orchestrated initial inquiry phases may be persistent and affect the entire future success of the scientific investigation and the mentorship.

Context is highly influential on enriching the dialogues between students and scientists when students are subjected to these arguments. As Schwartz, Lederman, and Crawford (2004) suggested, students develop knowledge and understanding of NOS when they are provided context about methodology and the activities through which science progresses. Here our scientists undertook that role and provided the context regarding nature of inquiry under the investigation and data gathering methods. Therefore, scientists can provide an important element of authentic inquiry that normally do not present in classroom environment.

Our findings regarding the influence of scientists' occupation and subject of the study to their understanding of science and the way they inform students about that understanding revealed that scientist occupations (e.g., being a graduate student, college affiliated professor or working in NGOs) make a difference. This finding is consistent with the previous studies and the developing literature about the discussion on whether understanding of science is universal or it is subject and context depended. In science literature there is a disagreement about nature of science (Alters, 1997a; Alters, 1997b). Irzik and Nola (2011) suggested that students should be taught science in a family resemblance perspective instead of a universal science understanding called consensus view. In our study, for instance, the scientists worked in genetics modules exhibited different understanding of science based on the evidence present in dialogues. On the other hand, scientists in other modules, such as photosynthesis, C-ferns, and wonder of seeds, represented a common understanding of science consistent with family resemblance perspective. Thus, even within a specific field of science, in our case it is biology, there is variation in terms of its features represented and explicitly mentioned by scientists in naturally occurring dialogues. Further studies may test this hypothesis and come up with generalizable conclusions that can contribute to the literature of science education. Also, scientists' occupation had an effect on their way of representing their science understanding. As Wong and Hodson (2008) found, scientists' understanding of science may be more context dependent and changes depended on their personal experiences and how they experience science in their environments.

Scientists and educators who are willing to design and implement partnerships like *PlantingScience* should take argumentation and discussion in to account, because scientists' engagement in dialogues with students creates more opportunities for students to express themselves and reflect on what they are doing in scientific inquiry under the guidance of their mentors. As Moss (2001) suggested, for many students the quality of their science experience in school is critical because their school experience may be the only formal exposure to science that they will receive in their lives. In this sense, their experience carrying out an authentic science inquiry with real scientists may be the only chance they will have in their life.

In overall, our findings were derived from constant comparison approach and were independent from preexisting theories due to the nature of grounded theory. However, there is a very good match between categories emerged in our model and previous findings in the literature. For instance, In a Delphi study conducted by Osborne, Collins, Ratcliffe, Millar, and Duschl (2003) involved scientist from Royal Society, the researches came up with nine themes representing scientists' views of science. These were (1) scientific method and critical testing, (2) creativity, (3) historical development of scientific knowledge, (4) science and questioning, (5) diversity of scientific thinking, (6) analysis and interpretation of data, (7) science and creativity, (8) hypothesis and prediction, (9) cooperation and collaboration in the development of scientific knowledge. As you notice, some or most of the themes share the same name with the categories and sub categories we found in this study. Although, our purpose before studying this research was to investigate the naturally occurring dialogues without using predefined categories, there is a big overlap between this study and the existing literature that provides a theoretical crosscheck.

Use of language and role of discourse in a student-scientist partnership has great importance. When scientists prefer to use a scientific language paying attention to terms and operational definitions, students tend to use a similar language to communicate with their scientist mentors. It is very normal to expect that because when we assume that science is a human activity and endeavor, language should be critical element of it. As Newton et al. (1999) stated active participation in scientific discourse is central to science learning. Developing an understanding of science and its language components require students using its discourse as practicing (Duschl & Osborne, 2002).

One purpose of this study was to investigate and understand how scientists contribute to students' understanding of science via mentoring. The strategies category, which explains social function of the scientist in the partnership, revealed that scientist not only provide the context and the elements of inquiry but also undertake a role and serve as a social element within the culture created in *PlantingScience* partnership. As Lemke (2001) mentioned "Scientific study of the world itself [is] inseparable from the social organization of scientific activities" (p. 296). Our findings are parallel to the findings in literature investigated scientists' distinct roles in guiding students' scientific practice. It was concluded that scientist had distinct functions and behaviors (e.g., modeling, task structuring, questioning, reflecting, and instructing) as they assist students' science practices (Peker & Dolan, 2012, 2014). Therefore, scientist-mentors who are willing to be part of student-scientist partnership projects and the ones who had that experience in such programs should consider their social functions along with being a mentor for students.

Limitations and Future Research

The emergent theoretical model of scientists' contributions to students' understanding of science via online mentoring is this author's interpretation of 36 scientists mentoring students doing scientific inquiry with student teams. As it is frequently the case in qualitative research, the results of this analysis are unique to the particular investigator, participants, and context of this study. The transferability of this theoretical model for scientists' contribution to students' understanding of science in a partnership model takes place as the reader examines these results in the context of specific circumstances of interest.

Grounded theory, in nature, attempts to develop a general, abstract theory of a process (Creswell, 2003) and it aims to provide clear hypothesis to be verified in future research, in quantitative studies if appropriate (Glaser & Strauss, 1999). In this sense, results of this study, a model representing the process of scientists' contribution to students'' understanding of science, clearly described that process in details in order for reader to gather as much as information to be tested and verified in future research in science education.

Limitations can be defined as the weaknesses of the study that we cannot control. For this study, sampling and time could be defined as two main limitations. Since we used theoretical sampling approach, which is the most convenient and highly suggested sampling approach for grounded theory, our findings cannot be generalized to other partnership projects and to the whole *PlantingScience* project. However, using 100 randomly selected groups from last three years minimized the effect of the limitation and provided a homogenous participant group. The second possible limitation was that *PlantingScience* project involves student teams from different grade levels such as middle school high school and even college. This grade level range could be defined as limitation. However, since out purpose in this study was to investigate how scientists talk about science and how they explain it to students, the variability provided more information and extended scientists' explanations. As stated in the method section in detailed, the participants were selected from *PlantingScience* teams enrolled in the last three years of the project. However, this selection has been made based on the assumption that the initial years of the project were spent on implementation and workshops and last three years would provide more reliable and consistent information to the analysis. This characteristic could be defined as one of the delimitations for this study.

Significance and Implications of Study

There are three main outcomes of this study. First, the results revealed how scientists talk about science and how they, as practitioners of science, explain nature and features of science to students. These findings allowed us to see if science educators' understanding of science that has been studied and theorized in last decades is really overlapping with scientists' version of science. Second, the results reflect sociology and culture of science from scientists' perspective that is missing in formal schools settings. Finally, the results regarding qualitative comparison of scientists' background (e.g., occupation and way of practicing science) and subject of inquiry provided information about whether science is universal or more pluralist in terms of its core and dynamic aspects. In terms of its significance, this study has three possible basic implications for science teaching. First, it has potential to give us information and clues about what real scientists talk about science when they are doing authentic inquiry with students. When we consider teachers' inabilities to teach authentic science and nature of science according to literature, the findings of this research can be implemented to school setting to make science education more authentic. Second, we can conceptualize what the core and dynamic features of science are, especially botanical science. Third and finally, results of this study may provide insight about the processes included in a partnership model in order for educators to design projects considering what scientists experienced in *PlantingScience* as scientist-mentors. Especially the scientists who have willingness but lack of experience in science teaching can benefit from the process explained here.

CHAPTER IV

SCIENTISTS' CONTRIBUTION TO STUDENTS' SCIENCE PROFICIENCIES VIA ONLINE MENTORING

Introduction

Today's science education has become more interdisciplinary and includes new actors, including private organizations and scientists playing new roles as contributors in K-12 classrooms of science teachers and students. Especially in past two decades, there have been many attempts to involve scientists in science education research and practice. Scientists' contributions to science education have gone beyond serving as role models. Recent policy documents regarding science education and its future explicitly feature scientists as part of science education. For instance, in a recent National Research Council report, involvement of scientists in science education was stated as a way of showing students how scientists do science for the development and integration of 21st century skills into science teaching (NRC, 2010). Parallel to these developments, ongoing research has revealed that student-scientist partnership models can have a significant effect on educational outcomes in different dimensions, including students' content knowledge and attitudes towards science (Houseal, 2010); content knowledge and skills in working on science fairs together (Baumgartner et al., 2006), and students' perceptions about scientist and their decisions about choosing science as a career (Marx et al., 2006). More recently, Aydeniz et al. (2011) investigating the effects of apprenticeship-based research programs in which students worked with scientists on authentic science activities found positive effects of the program on students’ inquiry skills.

Theoretically, scientists’ contribution to student learning can also be explained by the term “cognitive scaffolding.” Goldman et al. (1999) described cognitive scaffolding as a support structure for thinking and explained it as an analogue to physical scaffolds used in construction. In this sense, scientists’ interactions with students who are novices in science can scaffold (i.e., enhance and support) their skills and understanding. Recently, Peker and Dolan (2012) conducted a study investigating in depth practices of scientists and teachers as they helped students during an authentic inquiry activity. These researchers used conversational analysis to examine naturally occurring dialogues between students, scientists, and classroom teachers. According to the results, scientists and teachers used several strategies and functions to support students’ meaning making. Scientists' functions varied from increasing conceptual understanding, playing the role of knowledge authority, and promoting the idea of scientific community to organizing ideas, increasing accessibility of knowledge, and checking students’ knowledge and offering ways of knowing. Different from teachers’ contributions, scientists provided epistemological and pedagogical aspects of meaning making to students, which included explaining the aspects of the nature of science (NOS) and natural phenomena.

Scientific Proficiency Framework

The NRC released *Taking Science To School* (Duschl et al., 2007), a synthesis of research from the learning sciences and science education. The report provided a framework for "scientific proficiency," which identified four intertwined strands of scientific proficiencies that students need to hold. In comparison to earlier attempts to define scientific literacy, this approach reflected a new understanding focusing on how children learn and how effective learning environments are designed and implemented. The four strands are (1) know, use and interpret scientific explanations of the natural world, (2) generate and evaluate scientific evidence, (3) understand the nature and development of scientific knowledge, (4) participate productively in scientific practices and discourse (Duschl et al., 2007; Duschl, 2008). This framework of scientific proficiencies highlighted the cultural basis of science and blended it with learning goals of science for all students (Duschl, 2008). As Duschl described : “The four strands of scientific proficiency reflect an important change in focus for science education, one that embraces a shift from teaching about *what* to teaching about to teaching about *how* and *why*” (p. 270).

Many factors may come into play to account for teachers' inabilities to support students' development and use of the scientific proficiencies outlined in the new framework. Research revealed that although teachers engage students in 4 strands of science proficiencies, they have limited science related background and do not feel confident about authentic science. (Minogue et al., 2010). Moreover, current classroom practices indicates that more than 65% of middle school science classes are teacher directed, based on lecture, demonstration and teacher directed discussions (Tassel et al., 2012). In such an environment opportunities for students to practice, understand and internalize science as a culture and practice are minimal. Furthermore, science teachers most commonly rely on teaching science the way it was taught to them, with expectations that students will "master" scientific information. In this more traditional method of teaching science, teachers pay little attention to students' understanding of science and scientific inquiry. Reasons for the lack of attention to the nature of science have been linked to research findings indicating that teachers as well as students do not hold sophisticated understanding of science and scientific inquiry (Abd-El-Khalick & Akerson, 2004; Abd-El-Khalick & Lederman, 2000). Additionally, teachers themselves may not have had opportunities to engage in authentic scientific inquiry themselves. If scientists were invited to contribute their perspectives and views about authentic science to students (Wong & Hodson, 2008), scientists as practitioners of science could be expected to play an important role in promoting the use and development of students' scientific proficiencies.

Additionally, individuals gain knowledge of themselves as active agents of a group and culture through active participation in a scientific community (Akerson et al., 2012). Sadler et al. (2010) found that student-scientist partnerships have positive effects on students' careers and learning outcomes. Outcomes included increases in students' understanding of the nature of science, scientific content knowledge, confidence and self-efficacy, intellectual development, skills, satisfaction, discourse practices, collaboration, and changes in teacher practices. Sadler and associates suggested that students' epistemological engagement in the process of science is critical to accomplish expected objectives. Sandoval (2005) further suggested that the discourse involved during inquiry should be analyzed in attempting to evaluate the quality of the inquiry.

Online Mentoring

How can scientists meet with students and communicate with them throughout an inquiry process, particularly when the norm of science learning is basically classroom based? Technology can provide an answer to this question, particularly in the opportunities that new Web 2.0 technologies provide for online collaboration and mentoring. Use of these kinds of technologies in science education at middle and secondary schools can offer a sense of participation in a collaborative working environment (Barab & Dede, 2007). Through technology, scientists can mentor students through all stages of the scientific inquiry process, and reduce the gap between the school science and "real science" (Osborne & Hennessy, 2003). Although access to expert scientists is a critical element of student scientist partnership, regularly updated web sites and disseminating information electronically can improve student motivation when direct contact is not possible (Evans, Abrams, Rock, & Spencer, 2001). In this sense, online mentoring becomes a necessity for more effective student-scientist interaction in big scale partnership models. Online inquiry environments that allow students work with real scientists are among the technologies currently used in some project around the world. One of the first early and large scale application was the *Global Learning and Observations to Benefit the Environment* (GLOBE) project, which has been used by 5000 schools over 60 countries through K-12 education (Finarelli, 1998). In the GLOBE project, students took real time measurement through hands-on activities and shared the data with worldwide science community via the Internet. In addition, the project website allowed students to communicate and collaborate with scientists and other students.

Context

The *PlantingScience* project offers many supports for teachers desiring to integrate the study of plants and authentic scientific inquiry into their classroom science learning experiences. The unique feature of the *PlantingScience* project is its capacity to match the research interests of plant scientists with small student inquiry groups of 4-5 students. Plant scientists mentor one to three student inquiry groups as the student groups progress through their authentic inquiry experiences. Mentoring occurs via the *PlantingScience* communications portal, designed by the Botanical Society of America (BSA) to facilitate online communication between scientist mentors and students. Scientist-mentors and students communicate asynchronously via an on-line computer platform. Students post journal entries, images, and other scientific data on their page, and scientist-mentors engage in dialogue with them about their experiments. The BSA sponsors this scientist-teacher partnership, which currently engages over 700 scientist mentors and over 9000 students to bring inquiry-based, hands-on plant science into the K-12 classroom (Hemingway et al., 2011).

Student inquiry projects can last up to six weeks with support from the *PlantingScience* team. On the average, scientists communicate about 5-8 times within an inquiry session, with a range of zero to eleven posts (Peterson, 2012). Scientists are often identified as the most remarkable element of the program, as they contribute up to six weeks of their time communicating with their inquiry groups on line. The investigation we report here reflects our desire to understand more about the scientists' roles regarding the strands of scientific proficiency as they interact online with students. We used the online records of discourse between scientists and their student inquiry groups to conduct a naturalistic study of online discourse to explore the ways that scientists help students make sense of their authentic inquiry investigations.

Knowledge Claim and Research Questions

Since scientific research does not occur in a vacuum, it is normal for students and teachers to access someone like a scientist to discuss questions and concerns in formal education (Evans et al., 2001). In this sense, we think that scientists can contribute to students' scientific inquiry experiences in science classes by assisting students as they understand scientific explanations and reflect on scientific evidence, and participate productively in authentic science experienced through a partnership model. For this investigation, we posed two questions:

1. How do scientists contribute to students' scientific inquiry experiences?
2. What are the cognitive contributions of scientists to students' authentic inquiry experiences with respect to the four strands of science proficiencies?

Method

Research Design

The current study is an example of embedded mixed method design in which I used quantitative elements to support qualitative findings. This mixed method study addresses how scientists contribute to students' science proficiencies through online scientist-student interactions on the *PlantingScience* platform. Mixed methods included an embedded multiple-case replication study and descriptive statistics that allowed the interpretation of collected data (Schreiber, 2008). According to Yin (2014), embedded multiple group case study designs provide more robust results compared to single case study design by replicating and confirming findings from studied group. The units of analysis (i.e., cases) for this study were 10 student-teams who participated in PS in the fall of 2011. One science teacher taught these students in two separate classes. Each student-team was partnered with a scientist-mentor volunteer who was assigned by the Botanical Society of America.

Site and Population Selection

Purposeful sampling was used in the qualitative section of the study, which allowed the selection of site and participants to best inform the question under investigation. A sample of 10 student teams of seventh graders enrolled in two different sections at a public school in a Southwestern U.S. state participated in the study. The teacher in the study had 25 years of teaching experience, a Master's Degree in Education, three years of experience in *PlantingScience* classroom implementation, and attendance at several summer professional development programs. Nine scientists voluntarily participated in the project as mentors for the 10 student teams. Three of the scientists worked as professors, four were science graduate students, and two worked for private industry. Scientists specialized in different fields such as plant biology, cellular biology, plant ecology, and plant physiology.

The teacher's classroom was selected for two main reasons. First, this study was part of a bigger research project examining different aspects of the the group. Second, as part of the research we had collected detailed information about the sample, such as classroom observation data sheets, videos, student artifacts, and online dialogues. These additional data sources allowed us to go to the source when needed.

Data Gathering Methods

The student-scientist online dialogues created asynchronously through the inquiry project were used as the primary data source. Additionally, students' online inquiry summaries, artifacts and teacher's portfolio including journals were used as supportive secondary sources. The online dialogues were public on the Internet at the time of the study. At the very beginning of the study, student inquiry groups in the teacher's sixth and seventh periods were identified. After identification, I obtained these groups' dialogues from the PlantingScience website, which were then pooled and printed.

Qualitative Data Analysis Procedures

Initially, student-scientist dialogues were read several times before they were processed. Then, the dialogues were segmented into smaller units or "raw bits" representing discrete and different events, as described by Lincoln and Guba (1985). The meaningful units were highlighted and coded. Then, I grouped codes to match one of the four strands of science proficiencies, which are grounded in NRC's *Taking Science To School* (Duschl et al., 2007) and *Ready, Set Science* (Michaels et al., 2008). A science proficiency rubric (Appendix A.), developed by Scogin, Ozturk, & Stuessy (2013), facilitated the process of clustering codes to allow the classification of each coded unit into one of the four strands of science proficiencies.

For the analysis, constant comparison method, which was originally developed by Glaser and Strauss (1999), was used to cluster codes to yield temporary categories and reduce the codes to themes for each of the four strands of science proficiencies. First, if the bit was similar to one already coded, the same code was applied; in cases where the bit was different from those preceding it, I applied a different code. I then clustered codes sharing a particular meaning to yield temporary categories and reduce the codes to themes. These themes corresponded to the four strands of science proficiencies identified and described by Duschl (2008).

Quantitative Analysis Procedures

As a secondary analysis, frequency counts obtained from the scientist's contributions to the dialogue were used as supportive elements to explore scientists' contributions to students' scientific proficiencies. Scientists' comments also were subjected to a constant comparison analysis, resulting in coded units also grouped under one of the four strands of science proficiencies. Then, I compared the frequencies of both scientists' and students' comments to investigate trends in the dialogues. Scientists' proficiency frequencies (Scientist-SP) were compared with students' science proficiency frequencies (Student-SP), and students' online inquiry performances. Students' online inquiry performance was measured using the *Online Elements of Inquiry Checklist* (OEIC; Appendix B) developed by Peterson and Stuessy (2011) for assessing students' inquiry performance in online environments. The OEIC checklist lists phases in the inquiry cycle, each of which is further elaborated with “elements” representing the quality of the students’ performance in the phase. For example, the OEIC divides scientific inquiry into eight phases: (1) immersion, (2) research question, (3) prediction, (4) experimental design and procedures, (5) observations, (6) analysis and results, (7) conclusion and explanations, and (8) future research and implications. A total of 40 elements distributed within each of the eight phases demonstrating students’ online inquiry performances. For this study, I calculated the percentages of total completion for all phases in the inquiry cycle, which served as the student outcome measure in this study.

Standards of Validation and Evaluation

Several different perspectives exist regarding the validity of a qualitative study. Approaches can change from philosophical lenses to methodologies to be applied. In our study, we used Lincoln and Guba's (1985) validity standards of “credibility,” “authenticity,” “transferability,” “dependability,” and “conformability.”

Members of the university-based BSA Research Team (of which I was a member) aimed to establish credibility of their findings through prolonged engagement in the project. We were active researchers in the *PlantingScience* project for over three years. For example, in my role as a researcher I have observed the classroom where the 10 student groups studied, where I video recorded and documented the inquiry process. I have also carried out several classroom observations in several states for other *PlantingScience* projects. Furthermore, I made contacts with *PlantingScience* teachers as I attended workshops and summer camps with them, including a focus group of

PlantingScience teachers that was held at an annual BSA meeting in Columbus, OH. In addition, I have studied scientists' dialogues in different studies for the project. These experiences helped me develop familiarity with the project context and its culture.

Many of the members of the BSA Research Team formed collegial relationships with both the teachers and some of the scientists in the project. This also helped ensure the team's understanding of scientists' views, which provided a peer group with whom I had many conversations regarding my preliminary ideas about research design, analysis techniques, and ultimately, the findings of the projects in which I was involved. All team members aimed to ensure the transferability of our findings by using purposive sampling and developing rich descriptions of research settings and details. Specifically, analyzing asynchronous dialogues allowed us to identify details of the discourse and who told what and how it changed through time, particularly as the online dialogues were recorded in such a way to allow us to identify the specific dates and times when students responded to a specific post. Basically, using the online dialogues allowed us to collect information about every detail of the online discourse between scientists and students.

Finally, the BSA Research Team aimed to establish credibility and dependability of our data analyses through peer debriefing and discussions about various coding frameworks used by team members in their own research investigations. For instance, one summer the seven members of the research team met weekly meetings for three months to guide our thinking and writing as we conducted our own studies regarding aspects of the rich *PlantingScience* environment. Finally, we aimed to establish conformability of our findings by reflecting on and discussing the results and limitations of the research in our conclusions.

Results

General Frequency Counts of Scientists' References to the Scientific Proficiencies

Before doing constant comparison analysis for the case study, I completed frequency counts for scientists' references in the dialogue corresponding to each of the strands of science proficiencies (Figure 3). According to the results, scientists mostly contributed to students' science proficiencies in understanding scientific explanations (38%: Explain) and generating scientific evidence (37%: Generate). They spent less time reflecting on scientific knowledge (19%: Reflect) and participating productively in science (6%: Participate).

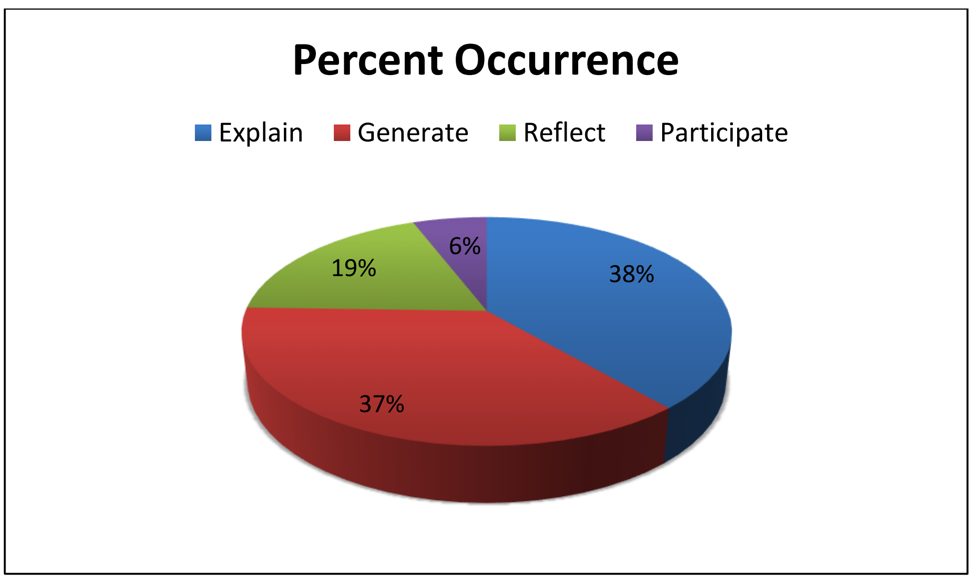

Figure 3. Frequency distributions of the science proficiencies through online dialog.

The results indicated that scientists served as a source of knowledge and guided students as they generate scientific evidence. These results were expected, as scientists performed the roles in the dialogues as the practitioners of real science, providing their knowledge and skills and helping students use the appropriate knowledge and tools to successfully progress through inquiry process. Details regarding each of the scientific proficiencies follow.

The Strand of Understanding Scientific Explanations

Providing knowledge mostly connected to daily life situations. Scientists often used explanations that were connected to the real life cases rather than providing students factual textbook information. This gave students a sense of connection between science and the life they live. Also, the information given was degraded to the level that students can easily understand. This also creates some kind of relatedness so that students can be involved in scientific discussion.

Examples:

> In some… if these types of plants the purpose of the fruit is to attract animals which eat the fruit and its seeds and excrete them in feces in another location. This carries seeds to other areas for the plants to grow.
>
> The seeds from inside the watermelon. A watermelon is like a[n] apple or an orange. The seeds are inside the fruit where they develop into mature seeds. The actual part of the watermelon that you eat is the plants ovary.

Inside of seeds there is a little plant called an “embryo.” In order for this little plant to grow it needs some nutrients, which comes from the cotyledon. You can think of the seed as a little baby inside a box with its lunch.

Checking students’ background knowledge by using Socratic questioning. One other role the scientists in the project undertake was checking students’ background knowledge before providing new information and this duty has been applied via questions.

Examples:

“ Have you discussed what plants require for germination?”

“What is inside those seeds? Are the contents of the seeds different for big seeds and small seeds?”

However, the way scientists used questioning was different than asking yes or no questions. When the dialogues were examined, it was obvious that the scientists mostly used Socratic questioning technique in which the aim was to make student reason and come up with new ideas instead of finding an answer passively.

Examples:

“Have you noticed that your seeds were different sizes when you started? Why do you think some seeds are big and some are small?”

“Can you think of a reason why a seed might need a hard protective covering?”

“Why might one type of seed need a helicopter wing (maple seed) while another seed need to really small (radish seed)?”

Asking questions also allowed scientists, who did not have too much experience with elementary and middle school teaching, to know about students' learning. It also served as a medium in which two sides know each other by finding a middle way.

Example:

" What have you learned about soil and the nutrients it contains? Why did you choose these? What are some of the properties of vinegar and coke compared to water?"

Trying to explain a situation or a phenomenon. Scientist tried to provide explanations about a phenomenon that students observed in their inquiry experiences. In other words, they provided information directly related to something happened or student observed during the experiment. This role was serving as a scaffolding tool, which allowed students not being interrupted due to some reason as they processed trough scientific investigation.

Examples:

" I am curious if you looked up the nutrient requirements of the type of bean plants you are growing. It might give you some insight into which treatment will affect the growth of the plants the most."

> If you are asking how long it takes to measure photosynthesis, that depends on the sensitivity of the methods you use. If you are measuring the uptake of carbon dioxide by the leaf using a gas analyzer, you can detect photosynthesis over a time span of seconds.

Providing explanation to students by connecting it to students' experience. Although this theme is similar to the previous theme explained, in here scientists provided extra information about something by connecting it to students' life experiences. However, the information given was more general and did not serve as scaffolding.

Examples:

"Real garbage yards typically receive full sun nearly all day. The kind of trash in the trash can/garbage yard will play a role in the survival of your seed."

"What you have growing is a fungus and fungi love sugar. Keep track of the fungus grows."

Providing methodological knowledge. The scientists in the project also provided methodological knowledge to the students doing inquiry. The knowledge provided were more related to the techniques and methods rather than factual knowledge related to context.

Examples:

> Also, because the volume of air in an entire room is quite large and it's made up of a lot of different gases, it might be easier to grow your seeds/plants in a small plastic bag or container, and then add extra CO2 to one of them.

"However, this might be a difficult experiment to pull off using animals as the CO2 source for a whole room. You'd need LOTS of extra animals in the second room in order to detect any increase in CO2 levels!"

"Regular incandescent bulbs (typical old light bulbs) produce light by sending electricity through a thin filament of metal. This causes the filament to radiate light and heat."

The Scientific Proficiency of Generating Scientific Evidence

Checking and confirming procedures regarding inquiry. Based on the evidence obtained from the dialogues, scientists checked and confirmed students' actions regarding experiment and procedures. They usually avoided directions and provided advice by using if statements such as "if you do this… it would be like…". Also, scientists wanted to get feedback from students by asking questions and providing responses to the groups that needed help. In other words, scientists contributed the inquiry process by following up students' experiments.

Examples:

"If you set up a mock garbage yard will you supply it water for moisture or only rely on rainwater as it would receive in a really garbage yard."

"Are you sure that growth of plants in different soil will be due only to the soil type."

"What do you all think might happen if you cut a seed in half, and then tried to make it sprout?"

"How much water was in the cup? (Was there a lot of water in the cup, so that the seeds were covered? Just tiny bit of water? Or something in between?"

Emphasis on research question and predictions. Another focus of the dialogues regarding the "generate" strand of the science proficiencies was the scientists' emphasis on research questions and predictions in a scientific investigation. Especially, the scientists tried to help the students keep close to their predictions and hypothesis. They often used explicit statements to make the students' prediction and hypothesis clear. They also wanted students to define, describe, and type their predictions and hypothesis.

Examples:

"Do you have any ideas about what you might like to focus on?"

"It's always good to have some reasons to go along with your predictions. Predictions without reasons are just guesses!"

"What are you going to measure to see if your hypothesis is supported or not?"

"Do you have a hypothesis as to which seed will germinate the faster? What makes you think that seed will grow more quickly?"

"I am curious as to what interests you about plants and what types of scientific questions you have about the world around you."

Experimental design. The scientists often emphasized on importance of experimental design and design procedures. They often tried to get information from students about the next step in the experiment and requested information about the experimental design.

Examples:

"I'm looking forward to hearing more about your experimental design!"

"What is the next step in your experiment?"

Data collection and measurement. Data collection and measurement emerged as the two important elements of inquiry according to the emphasis given by the scientists in the *PlantingScience* project. What students measure, how they record and evaluate their measurements, and what types of observations are used were some of the comments that scientists frequently mentioned in their conversations with the students. In this sense, the importance of measurement and data collection was highly reflected on student-scientists dialogues. Moreover, number of codes obtained for this theme was the highest for the generate title.

Examples:

“How will you measure the growth rate?”

“You could record the initial weights of each seed you plant and provide each with identical growing conditions (amount of water, soil, light etc.).”

“Each day you could measure the plant heights and see if the initial growth is related to the initial seed weight”

“Thinking ahead to consider how you will measure your plants and how you will use those measurements to evaluate which seed is fastest will be of great help in the long run!”

Emphasis on controlled experiments. The emphasis on controlled experiment concept was another emerging theme that we obtained from our analysis. There was a clear interest on the concept of controlled experiment. Most scientists expected to see controlled experiments and wanted students to have a control group in their experimental set-ups. Especially, they stressed the concept of a control group and importance of it in an experimental design. There were couples of examples indicating this type of approach.

Examples:

“There are a few things you should make sure of with this experiment. Remember to plant all the seeds at the same depth so that some don’t have an advantage over others –also make sure they all receive equal amount of water during growth.”

“If you held this variable constant what would it be called? What other conditions did you keep the same?”

“For example, rather than only planting one seed (or even three) in one pot, plant several in several different pots.”

Revision of experiment and design. The scientists participated in our sample provided opportunities for students to revise and to think of possibilities can be revised in student inquiries. They also created opportunities for students to evaluate the results and the whole process by asking questions.

Examples:

“Can you think of another reason why plants grow under heat lamp may turn out different than those grown under the regular light bulb?”

“Your change in your research question seems like a good idea. I have a few follow up questions.”

The Scientific Proficiency of Reflecting on Scientific Knowledge

Building a scientist’s view in students’ mind. One of the scientists’ roles in *Planting Science* project was to draw an image of science in students’ mind and allow them to interact with real scientists. According to the results, we see that scientists not only helped students with carrying out experiment, but also they constructed an image of scientist in their dialogues with the students. They used statements like “a good scientist would do…” or gave examples from their own experiences.

Examples:

“Just about all scientists (including me!) measure using the metric system with meters for lengths and liters for volumes. Once you get used to it, it’s much easier to work with centimeters than inches.”

“All scientists do this, even us old ones!”

“I know this may seem like a lot to think about, but a good scientist tries to think about all the crazy outcomes that may happen in this experiment, and then tries to adjust the experiment to handle those crazy outcomes fairly and without bias.”

Importance of accuracy and reliability. One another finding of the study was the scientists’ emphasis on reliability and accuracy of the information students gathered. They essentially indicated that science is not doing experiment for the sake of experimentation. It is rather collecting reliable and accurate information through controlled experiments. In this sense following examples can give us some idea about how the scientists contribute proficiencies regarding accuracy and reliability.

Examples:

“A lab notebook updated daily is an important part of a scientist’s job. It is important to have accurate and detailed notes – of both things that work and things that don’t work. This way you can look for patterns and try to figure out what is happening.”

“I also suggest that you replicate your experiment by having several pots (containers) for each treatment. So rather than having 10 seedlings in each pot I would put one seedling in each of 10 pot I would put one seedling in each of 10 pots and have several pots for each of your chosen treatment."

"Having replicates for each group is a good idea because measurements for any one individual can be affected by a lot of different things, but measurements for a few individuals can be averaged and give you a better idea of what is really going on with that test group."

"Make sure you record what happens even when you decide to restart, all that data may prove to be useful when you write up your results."

Wonder and excitement in science. Scientists explained science as an exciting thing and stated that wonder is a part of it. They informed students about the wonder of science and their willingness to be part of it.

Examples*:*

"I hope you're excited to start the science!"

"The most exciting phrase to hear in science, the one that heralds the new discoveries, is not 'Eureka'!"

"So let me ask you a question: what have you always wondered about pants? Is there something about plants that you've always thought was interesting."

Building perception of science "science is all about…". Scientists also built perception about what science is all about. They shared ideas about some characteristics of science as they engaged in dialogues with students.

Examples:

"If it's science-related, it is a fair game!"

"Science is all about discussing ideas and communicating new information."

"Making observations and asking questions are the first parts of the scientific process. The last steps to every experiment is to draw conclusions and come up with future experiments"

"The good thing is we learn from our mistakes and usually end up with a stronger experiment."

Possible revisions for further studies. The scientists spent time on reflection after the students completed the inquiry activities. In this respect, the scientists often initiated a reflection discussion about the procedures completed and the results obtained. They sometimes used follow up questions to get feedback from the students.

Examples:

"What sort of things did you learn from your experiment? Is there anything you would do differently next time?"

"Why did you predict the way you did?"

"Do you think your conclusions for mung beans would be the same for a different type of plant?"

"Did the plants in all the treatments die? Do you know why the plants died? Were they given enough water and light to grow?"

The Scientific Proficiency of Participating Productively in Science

Emphasis on collaboration. The emphasis on collaboration was one of the themes emerged during the analysis of the data for the participating productively in science strand. Scientists provided information regarding their experiences in real life as a scientist. They talked about how they work with others and how working with others can affect their profession.

Examples:

"We have our own research projects, but usually work in groups and collaboration is highly encouraged."

"The way we can take advantage of the expertise of our coworkers and can apply what they know to better our work."

"We also do a lot of talking to get many opinions and perspectives as we are planning research."

Going to external sources to get new information. The second theme that we had as a result of constant comparison is scientists' referral to other external sources. This theme reflected that science does not occur in an isolated environment and on the contrary it requires publications of the other people and the knowledge of other studies. In our case the scientists wanted the students to get information from other sources like *Google* and articles on the web.

Examples:

"This link shows the major parts of the internal structure of seeds."

"I bet you could do a quick google search to find out."

"Follow the link to Wikipedia has some pictures of it"

However, the number of codes regarding the participation proficiency is less that the other three when it is compared, because the rubric does not count students' and scientists' participation in online dialogues as participation. For example, we did not count the number of responses as participation; instead we used the codes explicitly mentioning or encouraging participation. Further analysis could be done to reflect the participation of the platform and scientist to students' inquiry experience.

Descriptive Statistics as Supportive Measures

This study used an embedded mixed method design, including quantitative data in it as a supportive element. My purpose was not to make generalizations about the findings and interpretations by using statistical analysis. Instead, I aimed to provide a general idea about this particular case by giving details including numbers and information about other variables. As Schuyler W. Huck (2004) mentioned, descriptive statistics can be considered as the picture technique "for summarizing data that produce a picture of the data" (p. 17). In a similar way, my purpose was to add more information to the picture of the ten groups. First, I used two online data sources to compare scientists' SP frequencies (which were obtained from the online dialogues) with students' SP frequencies (obtained from the online inquiry summaries). When we assumed that the scientific proficiencies of Explain, Generate, Reflect, and Participate dimensions would progress linearly over time; graphically the gap between scientists' SP and students' SP frequencies decreases. In other words, students became more engaged in science proficiency dimensions as they progress through inquiry except participate dimension. They talk more about science proficiencies in their inquiry summaries as they engaged in dialogs with scientist mentors (Figure 4).

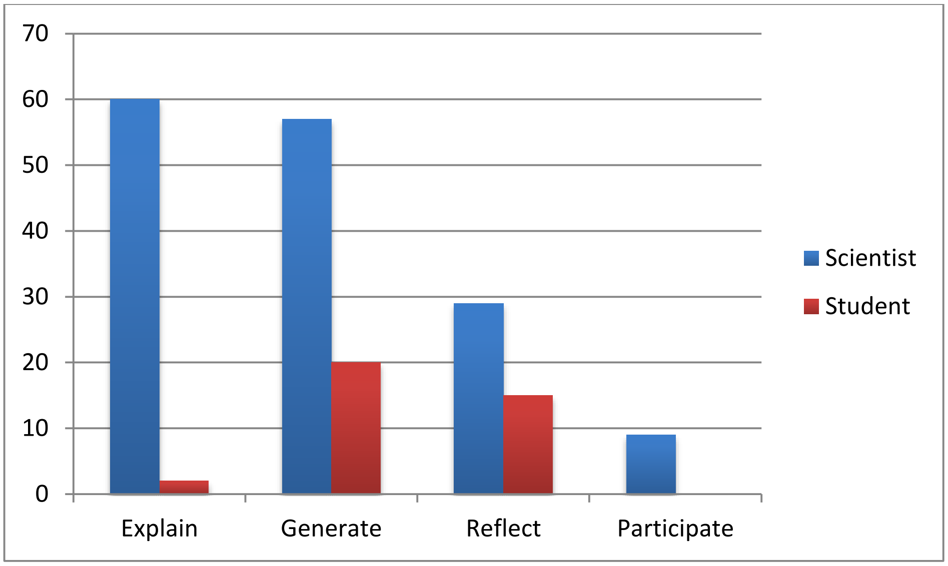

Figure 4. Comparison of students' and scientists' science proficiency frequencies for each strand.

For more accurate results, I examined the ratio between students' and scientists' SP frequencies for each strand, because a dialogue includes two parties and I think the ratios between scientist and student talks can give a better picture about any change in students' engagement in dialogs about SP. Numbers also supported the claim that I mentioned above. Numerically, the ratio between scientist SP frequencies and student SP frequencies for the *Understanding Scientific Explanations (Explain)* dimension was 30. For the *Generating Scientific Evidence (Generate)* strand we saw the ratio was 2.9. For the *Reflecting on Scientific Knowledge (Reflect)* strand it was 1.9. For the *Participating Productively In Science (Participate)* strand of science proficiencies it was around 9.

In the next step, Scientist-SP mean scores were compared with Student-SP mean scores and OEIC percentage means. When groups were ordered by Scientist-SP scores as low, medium and high, Student-SP means and OEIC percentage means followed the same pattern. As the scientists' emphases increased on their mention of science proficiencies, students' emphasis also increased. In other words, students were more engaged in science proficiency related dialogs when their scientists' mentors talked more in regards to proficiencies. This finding indicated that scientists had a role that promote and assist students develop science proficiencies. Also, as scientists' emphases increased on their mention of science proficiencies, students' inquiry performance also increased (see Table 4). The pattern suggests the potential power of the scientists' contributions in the dialogue, even though the results are ones of association not causality. As indicated in Table 4, there was almost one standard deviation difference between high and low groups regarding their SP and OEIC percentage means. Figure 5 graphically represents this tendency. The data suggest that the scientists had the power as the leader in discussing scientific proficiencies. Scientists assisted students to participate productively in scientific proficiency related discussions as students work on their inquiry projects. The data and visually graphs suggested that scientists had a role in promoting discussion among students about proficiencies. For example, the three scientists contributed minimally in the *Low Group* to the dialogues in regard to science proficiencies and student comments were also the lowest (almost non-existed among the 10 groups) in this group. Their inquiry performance scores were 22 percent points lower than those who were mentored by the *High Group* of scientists. According to the nature of the study these findings were specific to the case of this one teachers' student inquiry groups; and mean comparisons cannot be generalized to other populations. However, descriptive statistics well supported our arguments focusing on the ways in which scientists contribute to students' understanding of the scientific proficiencies.

Table 4

Mean Comparisons of the Groups When They Grouped as Low, Medium, and High by Scientist's Science Proficiency Scores

Rank	N	Science Proficiency Scientist Mean	Science Proficiency Student Mean	OEIC % Mean
High	3	21.0	5.3	64.3
Medium	4	16.7	4.3	54.0
Low	3	8.3	1.0	42.0
SD		*5.7*	*2.6*	*20.0*
Max.		*22.0*	*8.0*	*85.0*
Min.		*4.0*	*0.0*	*8.0*

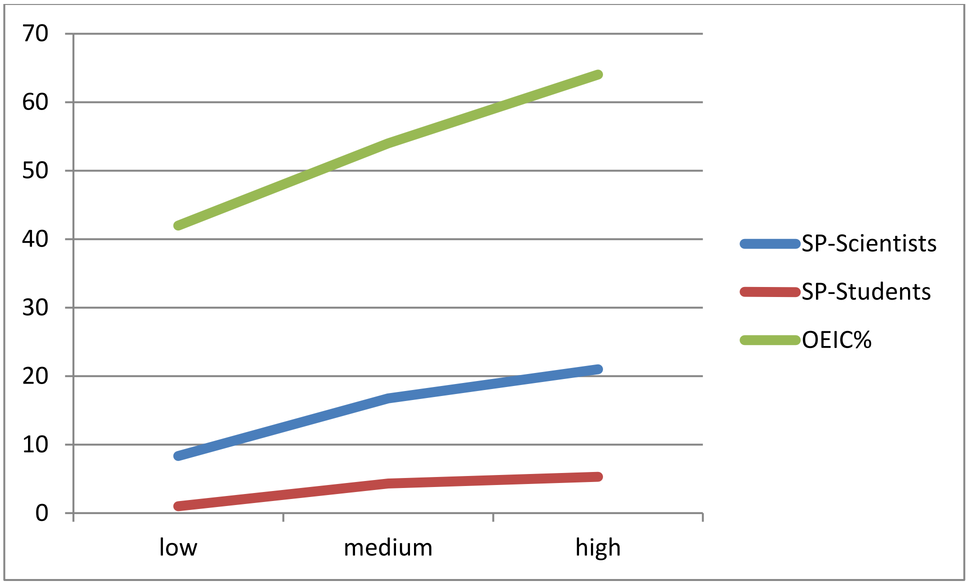

Figure 5. Line graph comparisons of the mean scores in low-, medium-, and high-scoring groups of Scientists' Science Proficiency Counts, Students' Science Proficiency Counts, OEIC scores of Student Teams. *Note.* SP-Scientists = scientists' science proficiency frequency counts, SP-Students = students' science proficiency frequency counts, OEIC% = online inquiry checklist percentages.

Conclusion and Discussion

Results of the analysis revealed that scientists participating in online authentic science with students made noteworthy contributions to students' online inquiry experiences in all four dimensions of science proficiencies. Although two categories, *Understanding Scientific Explanations* and *Generating Scientific Evidence*, had higher percentages, scientists contributed in all categories as they engaged in dialogues with students throughout the six weeks inquiry experiences for these ten student inquiry groups.

The purpose of this investigation was to explore scientists' contributions to students' scientific proficiencies, including interactions and patterns characterizing frequencies of occurrence in scientists' and students' emphases on scientific proficiencies, and with students' inquiry performance. Investigation of scientist-student interaction revealing the essence of the dialogues between the participants in such a big scale project is important. In this sense, discussions that follow can help in building models of new scientist-school partnerships for the future engagement of scientists in K-12 education.

According to the results in this small-scale study, scientists were most likely to engage in discussions about the proficiencies of *Understanding Scientific Explanations* and *Generating Scientific Evidence*. Unique to scientists' contributions were the connections they made between scientific knowledge and daily life experiences, rather than reciting factual information easily found in textbooks. Scientists also explained concepts and used conceptual models to explain scientific phenomena and commonly used Socratic questioning to promote students thinking and make them active learners.

The teaching approaches used by scientists in the mentoring context are rarely observed in traditional science classrooms. Traditionally, teachers use informative approaches (Tassel et al., 2012) and spend most of their time in class on knowledge-based instruction and on procedures in science. Nor does classroom discourse support reflexive discussions; science in traditional science classrooms is teacher-driven, not student-centered (Newton et al., 1999). Unlike the traditional science classroom, the *PlantingScience* environment largely supports critical thinking and active participation of the students, while they build models of understanding to explain natural phenomena scientifically. Scientists also gave emphasis on critical elements and concepts of generating scientific evidence, emphasizing research questions, predictions, experimental design, and controlled experiments. They used explicit statements to encourage students to be aware of these concepts and application of them.

Another role that scientists assumed was related to their profession as scientists working within the world of science discovery. Scientist mentors consistently attempted to introduce and build concepts of scientists and science in students' minds by discussing what science is all about and sharing their experiences, their own excitement about science, and their strategies in doing science as a practitioner of science. With all the results obtained from our analyses, we concluded that scientists as practitioners of science can play an important role in student learning by explaining their views of authentic science, similar to the research findings of Wong and Hodson (2008). In addition, scientists encouraged students to collaborate and get knowledge from external sources as it is done in authentic science, explaining how scientists work collaboratively with others in their own professions. Scientists gave examples from their own research and practices as part of the dialogue-sharing, mentoring experience. The discourse between scientists and students groups was reflexive and productive in its nature.

Moreover, descriptive statistics allowed us to observe the degree of difference among the student inquiry groups in the study. As we had ten groups in our sample, dividing them into three groups allowed us to observe differences between groups characterized as being mentored by scientists who were more or less active in offering students’ opportunities to learn about and with science proficiencies. Comparison of means revealed that student groups with more active mentors talked more about science proficiencies in their inquiry summaries; these groups also scored higher on the inquiry performance measure. Although these findings do not imply generalizable conclusions, the results and indications reported here can be used to support further studies. Our use of descriptive statistics helped us to clarify the picture painted by the case study of this single teacher's *PlantingScience* classroom.

To sum up, the results of the online dialogue analysis from the scientific proficiencies perspective revealed that scientists contributed to the authenticity of students’ science inquiry experiences by encouraging them to understand scientific explanations, generate scientific evidence with them, reflect on scientific knowledge, and participate productively in scientific discussions. Our analysis provides evidence that scientist mentors can provide support for all dimensions of science proficiencies as students engage in authentic inquiry, indicating a role more expanded than historical conceptions of "mentor" or "role model." The results of the study can also be important for new scientist mentors not familiar with science teaching in K-12 classrooms and can provide support for more elaborate studies based in theory and using both qualitative and quantitative measures to explore the effectiveness of mentoring strategies in broader classroom contexts.

CHAPTER V

CONCLUSION

This dissertation as a whole aimed to investigate scientists' contributions to students' inquiry experiences engaged through online mentoring by (1) examining the existing studies and theories in the literature, (2) generating a theory from working student-scientist mentorships, and finally (3) exploring how a specific case, group of individuals, experience it through mentorship. Methodologically, the extensive literature review about benefits of scientists to science teaching and learning from a sociological and philosophical standpoint allowed me to construct solid foundations for the dissertation study. Based on the findings highlighted in the related literature, the need for a model and/or a theory grounded in student-scientist partnerships has emerged. Therefore, grounded theory approach was used to generate a theory about student-scientist partnerships delivered through an online environment. Finally, a mixed method study approach allowed me to examine implications of the partnership and its outcomes in a small school where students shared the same environment and were subjected to the same mentoring opportunities. This mixed-methods study using case study as the main research approach revealed associations between scientists' comments regarding science proficiencies and students' responses within the dialogue and on a measure of inquiry performance. As a result, the process followed a funnel approach by narrowing down the research about student-scientist partnership to a point where a grounded theory study needed to explain how student-scientist partnership has occurred. The mixed method study brought it to a point in which a specific case was explained and scientists' contributions to students' scientist partnership were discussed based on specific examples.

Chapter II provides a review of the literature put forth to fill the gap of information exploring how scientists reflect their understanding of science to K-12 students when they work together in a partnership model. This review pointed out three main questions regarding student-scientist partnerships via online mentoring: (1) What do scientists say about science when they engage in online dialogue about students' inquiry projects? (2) What are the connections between scientists' demographics, the subject of the inquiry, and the way they explain the nature of science? and (3) What is the relationship between the quality of students' inquiries and what their mentors reveal about the nature of science in their dialogues? This literature review can provide benefits to others, including other science educators and those working in the fields of instructional technology and Science Technology Engineering and Mathematics (STEM). This review can be particularly help in that it integrates philosophical, sociological, and practical dimensions of scientists' contributions to teaching and learning science.

Chapter III aimed to investigate how scientist and students engaged in scientific inquiry and in which ways they interacted with each other in a scientific inquiry project through online communication. The results of this study revealed the educational, social, and cultural means of interaction between two parties, students and scientists. Also, investigation of various cases allowed us to better understand the essence of nature and culture of from practitioners' perspective. Moreover, the grounded theory approach allowed freedom to conceptualize and theorize the student-scientist interaction process without moving over the tracts of existing theories. There were three main outcomes for this study. First, the results enabled us to see whether science educators' understanding of the nature of science, studied and theorized in the last three decades, really does overlap with scientists' versions of understanding of science. Second, the results reflected the sociology and culture of science and scientists that are commonly missing in formal schools settings. Finally, a qualitative comparison of scientists' background (e.g., year of experience, academic title, field of study, etc.), and topic studied in the inquiry provided information about whether science is universal or more pluralist in terms of its core and dynamic aspects.

The purpose of Chapter IV was to explore scientists' specific contributions to students' scientific proficiencies using a contemporary framework of science supported by the National Research Council and described by Duschl et al. (2007). Chapter IV revealed that scientists contributed to the authenticity of students' inquiry experiences by encouraging them to understand scientific explanations, generate scientific evidence with them, reflect on scientific knowledge, and participate productively in scientific discussions. The unique contributions of the scientists were the connection they made between scientific knowledge and daily life as the practitioners of science, connections not included in science textbook emphasizing the structure of scientific knowledge. Scientists also used different teaching strategies, such as Socratic questioning, rather than a science teacher's most commonly used teaching strategy, direct instruction. The descriptive statistics provided in this study revealed that student groups with more active mentors responded with more talk about science proficiencies in their inquiry summaries w and better performance scores on a measure of inquiry performance. The result of this study provided evidence that scientist mentors can provide support for students' science proficiencies thus expanding earlier notions of scientists' roles in K-12 science as merely role models or mentors. The results presented in chapter III can be important for new scientist mentors who are not familiar with science teaching in K-12 classrooms. The studies presented here can also provide insight and bases for further studies using both qualitative and quantitative methodologies to investigate partnership models.

This dissertation should not be considered independent from its content. *PlantingScience* is in no way a result of this study; on the contrary, it is the noble cause of my willingness to begin this dissertation study. Several reasons exist for the important and unique place the *PlantingScience* project occupies to my research as a whole. While face-to-face student-scientist partnerships may be limited to small group of students and scientists, the P*lantingScience* project creates opportunities for thousands of students to experience authentic science thorough online mentoring provided by real scientists. The project continues to make scientists' understanding of science accessible to many students who would not have ever had the opportunity to talk to a real scientist otherwise. Moreover, the project allowed me as a researcher to investigate, and most importantly, experience a culture including students, scientists, college professors, and researchers from partner institutions who met regularly, created intellectual artifacts, and spent their time teaching what they know about science to students in formal education.

This dissertation study sheds light to broader impacts of these individuals on student's understandings and proficiencies of science, which is one of the main goals of science teaching in K-12.

To sum up, this study is a product of my years of commitment and research within the context of this project to tell the scientific community about its uniqueness regarding science teaching and learning. I believe people such as educators, researchers, and organizations who have a willingness to design and implement projects including scientists and students from K-12 institutions will benefit from the conceptual framework that I offered in Chapter II – Literature Review, the theory of mentoring process offered in Chapter III, and the implications from the case study offered in Chapter IV. In addition, naturally occurring dialogues analyzed here reflect the important voices of scientists, so often missing in science education, in terms of the authentic practitioners' perspective about what science is and how it is done. Therefore, the significance and implication of this dissertation are not only limited to the answers of the research questions. Significance and implication extend to science teachers in classrooms across the world by providing detailed models and descriptions that can be used by teachers who have the technology to incorporate scientist mentoring into the classroom experiences they provide for their students.

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APPENDIX A

Science Proficiency Coding Rubric (Scogin, S., Ozturk, G., & Stuessy C. S., 2013)

BROADER IMPACTS: SCIENTIST-TEACHER PARTNERSHIPS

How do scientists enhance students' proficiencies in science through their online mentoring of independent student inquiry projects?

SCIENCE PROFICIENCY CODING RUBRIC[1]

E - By assisting students in UNDERSTANDING SCIENTIFIC EXPLANATIONS

1. To know, use, and interpret scientific explanations
2. To understand interrelationships among concepts
3. To use interrelations to critique scientific arguments
4. To learn the facts, concepts, principles, laws, theories and models of science

G - By assisting students in GENERATING SCIENTIFIC EVIDENCE

1. To generate evidence
2. To evaluate evidence
3. To build and/or refine models and explanations using generated evidence
4. To design and analyze investigations
5. To construct and defend arguments with evidence
6. To master the conceptual, mathematical, physical and computational tools to construct knowledge claims
7. To carry out scientific investigations
8. To engage in the processes of science (i.e., to ask questions, develop measures, collect data, etc)

R - By encouraging and assisting students in REFLECTING ON SCIENTIFIC KNOWLEDGE

1. To understand that scientific knowledge can be revised
2. To track and reflect on their own ideas as they change
3. To understand the nature of science
4. To understand how scientific knowledge is constructed
5. To understand that evidence and arguments are based on evidence as generated
6. To reflect on the status of their own knowledge
7. To experience what it feels like to do science
8. To understand what the game of science is all about
9. Understand that science is a search for core explanations and connections between them
10. To value explanations as they account for available evidence
11. To value explanations in generating new and productive questions for research

P - By encouraging and engaging students to PARTICIPATE PRODUCTIVELY IN SCIENCE

1. To skillfully participate in a scientific community in the classroom
2. To master productive ways to represent ideas
3. To master productive ways to use scientific tools
4. To interact with peers about science
5. To understand the appropriate norms for presenting scientific arguments
6. To practice productive social interactions with peers in the context of classroom investigations
7. To demonstrate motivation and attitudes to engage actively and productively in science classrooms
8. To emphasize doing science and doing it together in groups
9. To share ideas with peers
10. To build interpretive accounts of data
11. To work together to discern which accounts are most persuasive

[1]Adapted from Ready, Set Science!

APPENDIX B

Online Elements of Inquiry Checklist, adapted from (Peterson & Stuessy, 2012)

a. Immersion

Is there mention of information-gathering efforts that occurred before students posed their research questions?
Is there mention of prior knowledge or experiences that enabled the learners to question the relationship between variables?

b. Research Question

Is the research question appropriate for the context of the study?

Are variables of interest observable and/or measureable?
Is there explicit evidence that the research question is tied to prior knowledge or experience?

Is there evidence that the students chose their own research question?
Can the research question be answered within the scope and boundaries of the inquiry setting?

Is the research question logically linked to a prediction, hypothesis, or expectation?
If the question is causal in nature, is the research question testable through a scientific investigation?
If the question is causal, is a relationship between the variables the focus of the research question?

c. Prediction

Is there evidence that the learners have considered possible or probable outcomes to their investigation?

Is their evidence that a project outcome is based on prior knowledge or experience?

Is the predicted outcome reasonable in light of the research question that is being asked?

d. Experimental Design and Procedures

Did the research design enable the learners to answer the research question?

Is there evidence that student themselves developed research methods?
Is there a description of research methods in enough detail so that another research group could replicate them?
Did the learners mention confounding variables?
Are controls of variables mentioned?
Is there mention that the learners controlled for possible sources of error in their

observation methods?

e. Observations

Is there evidence that research events were recorded?
Did the learners describe what they observed?
Are data tables included in the inquiry project?
Did the learners describe or discuss the data table(s)?

Did the learners provide visual displays of their data such as graphs, charts, or pictures?

Did the learners describe or discuss the visual displays?
Do the visual displays follow accepted conventions?

f. Analysis and Results

Did the learners mention patterns or trends in the data?

Did the learners compare data across multiple studies from other student groups?
Did the learners mention unexpected results?
Was the data used to answer the research question?

g. Conclusions and Explanations

Are the conclusions of the experiment connected to the data that was collected?

Are the conclusions consistent with the data that was collected?

Did the learners support ideas about causality with data?
Is there mention of alternative explanations?

Did the learners compare their results to other studies' results?

Did the learners discuss the limitations of their research?
Did the learners justify their conclusions using data?
Is there evidence of an expressed model or knowledge claim that explains relationships among variables with the natural phenomenon under investigation?

h. Future Research and Implications

Did the learners discuss the implications of their study?
Is there mention of possible study revisions?