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EXPLORING THE NATURE OF SCIENCE CONCEPTIONS OF UNIVERSITY SCIENCE PROFESSORS USING THE FAMILY RESEMBLANCE FRAMEWORK

by
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ABSTRACT
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Over the past few decades, research has been conducted on the nature of science (NOS) which is considered a critical component for achieving scientific literacy. While most of the studies focused on exploring students' and teachers' views of NOS, limited studies were conducted to identify university science professors' conceptions of NOS. Previous studies conducted with scientists reported that they hold mixed conceptions of NOS, and the survey instruments used were mainly based on VNOS (Views of the Nature of Science) questionnaires which reflect a "consensus view" towards conceptualizing NOS. However, this view was criticized for providing students with a simplistic image of science. For this reason, the current study adopts a recent theoretical framework which is the family resemblance approach (FRA). FRA is a comprehensive framework that presents NOS in terms of cognitive-epistemic and social-institutional systems including eleven categories that embody classes of ideas about science that are either left out or partially addressed by previous NOS models. To our best knowledge, only one study was conducted with Taiwanese scientists to explore their NOS views using the FRA as a theoretical framework. However, this study extends the emerging literature on the FRA by exploring the NOS conceptions of university science professors in the Lebanese context. Participants involved are 35 university science professors who teach science-technology- and- engineering-related subjects. The study adopts a mixed-methods approach. A modified version of the reconceptualized family resemblance approach (RFN) questionnaire as well as semi-structured interviews were used as the data-gathering instruments. The findings revealed that the university science professors hold mixed NOS conceptions which are consistent with the FRA approach to NOS. While the categories of the cognitive-epistemic system were the most highlighted in the professors' responses, categories of the social-institutional system were less addressed. Interestingly, a new emerging theme related to epistemic affect was mentioned by two professors in the interviews. Implications for theory, methodology, practice, and policy as well as recommendations for further research are discussed in light of these findings.

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ABBREVIATIONS

Abbreviation	Definition
NOS	Nature of Science
FRA	Family Resemblance Approach
RFN	Reconceptualized FRA-to-NOS
VNOS	Views of the Nature of Science
VOSTS	Views on Science, Technology, and Society
VOSI	Views of the Nature of Scientific Inquiry
AV	Aims and Values
SM	Scientific Methods
SK	Scientific Knowledge
SP	Scientific Practices
FAS	Faculty of Arts and Sciences
FAFS	Faculty of Agricultural and Food Sciences
FM	Faculty of Medicine
FHS	Faculty of Heath Sciences
FEA	Faculty of Engineering and Architecture

CHAPTER 1

INTRODUCTION

Nature of science (NOS) has been a proliferating area of research in science education since the 1960s. The inclusion of NOS aspects in the science curriculum has been endorsed in recent reform documents across the world (BouJaoude, 2002; Lederman & Lederman, 2014; National Research Council [NRC], 2012; Next Generation Science Standards [NGSS] Lead States, 2013; Organisation for Economic Cooperation and Development [OECD], 2017). This was justified based on the rationale that achieving scientific literacy requires an adequate understanding of NOS. Despite the various efforts made to improve students' and teachers' conceptions of NOS, studies continue to show that both students and teachers still possess inadequate conceptions of NOS (BouJaoude & Santourian, 2010; Lederman & Lederman, 2014). To date, a significant body of research has been conducted to identify students' and teachers' conceptions of NOS. However, less attention was given to university science professors; also referred to as "scientists". Accordingly, this study will contribute to the limited literature conducted with university science professors by exploring their NOS conceptions using a recent theoretical NOS framework which is the "family resemblance approach" (FRA).

Background of the Research Problem

Various definitions were given to the construct NOS by the science education community, yet "it most commonly refers to the epistemological understandings of science including the nature of the scientific knowledge, and the values and beliefs inherent to its development" (Lederman, 1992). As a result, diverse philosophical models emerged to conceptualize NOS, one of which was the “consensus view”. The “consensus view” was characterized by seven key ideas about science which are: empiricism (scientific knowledge relies on observations), tentativeness (scientific knowledge is never absolute rather it is subject to change), subjectivity (scientific knowledge is influenced by the scientists’ background, experiences and beliefs), creativity (generating scientific knowledge involves human imagination and creativity), social and cultural embeddedness (scientific knowledge is influenced by the larger social and cultural context), the distinction between theories and laws (theories and laws are different kinds of scientific knowledge and one does not become the other), as well as the distinction between observations and inferences (observations are descriptive statements about a certain phenomenon that are directly accessible to senses while inferences are statements about a phenomenon that are not directly accessible to the senses). Additionally, this view disproved the scientific method myth by the fact that there is no single method that all scientists use to produce knowledge (Abd-El-Khalick, 2012; Lederman, 2007; McComas, 2004).

The “consensus view” NOS list just described leveraged consensus among philosophers, sociologists, and science educators who agreed that its seven aspects are relevant to K-12 students and should be incorporated into the science curriculum and taught effectively. However, this list had its shortcomings and was criticized for providing students with a general view of science. As a result, alternative perspectives were proposed including the “whole science” approach suggested by Allchin (2011), who argued for the inclusion of a set of dimensions that represent the foundations of reliability in scientific practice, and that are absent from the “consensus view” NOS list. These dimensions include, among others, the role of funding, motivations for doing science, social interactions among scientists as in the peer review process, the validation of new instruments and experimental practices, the influence of cultural factors on science such as the ideological, religious, gender, and racial issues, as well as different forms of misconduct. Another perspective was offered by Mathews (2012) who advocated for replacing NOS with "features of science" (FOS) to expand its scope beyond the focus on scientific knowledge. These features involve both epistemic aspects (experimentation, explanation, theory choice, and rationality), as well as philosophical aspects (feminism, realism, and constructivism).

A more recent conceptualization of NOS was provided by the philosophers Irzik and Nola (2011a; 2011b; 2014) as an alternative to the "consensus view". It is called the "family resemblance approach" (FRA) based on Wittgenstein's (1985) linguistic philosophy, who used the analogy of family resemblance to show that not all "words" can be bounded to specific features or functions. By applying Wittgenstein's idea of family resemblance to NOS, Irzik, and Nola (2011a; 2014) solved the demarcation problem of science by treating the various scientific disciplines as members of a "family" having certain common characteristics (domain-general characteristics). Yet, these commonalities (resemblances) are not sufficient to define science, especially with the presence of other characteristics which are unique to each discipline (domain-specific). To clarify this further, Irzik and Nola (2014) provide the example of experimentation, among other practices, to show that even though experimentation is a common characteristic shared by many scientific disciplines, it is restricted in a discipline like astronomy or earth science. Therefore, unlike the "consensus view", the FRA framework accommodates both the domain-general and domain-specific characteristics of science.

The FRA framework had several versions since its introduction into the science education research literature. In their original version, Irzik and Nola (2011a) focused on four categories that reflect the cognitive aspects of science: activities, aims and values, methodologies, and methodological rules, as well as products. In a revised version (2011b; as cited in Erduran & Dagher, 2014), they introduced a fifth component of social context including Merton's norms, social values, and research ethics. In a later account, Irzik and Nola (2014) transformed the fifth component into a social-institutional dimension including four categories: professional activities, scientific ethos, social certification and dissemination of scientific knowledge, and social values. The inclusion of the various cognitive, epistemic, and social aspects of science and their articulation in a wholesome manner gives the FRA its comprehensive and systematic nature. While the FRA model subsumes all aspects proposed by the alternative NOS models, it excludes part of Mathew's "features of science" model specifically, the philosophical commitments including realism, feminism, and constructivism. This makes the FRA a philosophically neutral model and hence gives it an attractive feature.

In a more recent version, Erduran and Dagher (2014) reconceptualized the philosophical FRA framework of Irzik and Nola by extending and transforming it for pedagogical purposes in science education. One of their significant contributions was the expansion of the framework to include three additional categories under the social-institutional system of science thus drawing attention to the fact that science is also a "social endeavor", which is influenced by several social and cultural factors. They are social organizations and interactions, political power structures, and financial systems. These additional categories serve a wider range of learners especially those who are not attracted to the cognitive aspects of science. Another significant contribution of the expanded-FRA model was the introduction of the "Generative Images of Science" (GIS) which are visual tools that help communicate key ideas about NOS and inform its pedagogical and instructional implications. Several terms were used to distinguish Erduran and Dagher's expanded-FRA version from its philosophical counterparts (Irzik and Nola's FRA version and Wittgenstein's family resemblance idea) such as expanded-FRA, extended-FRA and "Reconceptualized FRA-to-NOS or (RFN)" which was firstly used by Kaya and Erduran (2016, p.1118).

Regardless of the approach used to conceptualize NOS, teachers have an important role to play in conveying to students an adequate image of NOS, which is a critical component of scientific literacy (Lederman, 1992; OECD, 2017). To date, a substantial body of research has explored the NOS conceptions of K-12 students, pre- and in-service science teachers, and the results continue to show that both students and teachers possess inadequate understandings of NOS. However, limited studies were conducted with university science professors to identify their NOS conceptions (BouJaoude & Santourian, 2010; Lederman, 2007; Lederman &Lederman, 2014). These professors are scientists who are experts in their fields and perform research in their related disciplines. They are responsible for educating future citizens including those majoring in scientific or non-scientific fields and who will contribute to the development of their societies. For this reason, they have to have acceptable conceptions of NOS and be willing to communicate them effectively to their students, thus preparing them to become scientifically literate individuals. Accordingly, exploring the NOS conceptions of university science professors is highly valuable.

Previous studies conducted with scientists compared their NOS views to those of teachers and students (Behnke, 1961; BouJaoude, 1996; Elkhoury, BouJaoude, &

Elhage, 2014), and reported that scientists hold mixed conceptions of NOS which are often traditional ones. Such traditional views suggest that science aims to reveal factual truths about the world. Other studies explored the relationship between the scientists' views of NOS and their scientific disciplines and areas of research (Bayir, Cakici, & Ertas, 2014; Schwartz & Lederman, 2008; Ssempala &Tillotson, 2015). These studies also reported mixed conceptions and it was found that these conceptions had no relation with the scientists' disciplines. The third line of research conducted with university science professors investigated the extent to which these professors incorporate NOS aspects in their instruction (Karakas, 2009; Woitkowski & Wurmbach, 2019) and findings revealed that the professors prefer traditional teacher-centered strategies even though they are aware of the importance of incorporating these aspects in their teaching practices.

Statement of the Research Problem

Most of the aforementioned studies used the VNOS (Views of the Nature of Science) questionnaire as a survey instrument to assess the degree of NOS understanding (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002). However, the VNOS questionnaire reflects a "consensus view" towards conceptualizing NOS which was criticized for providing students with a diluted image of science. For this reason, the current study chose the FRA framework as its theoretical foundation. The FRA framework had its empirical contributions to the science education literature all of which provide evidence of the effectiveness of this new approach in improving the quality of science teaching and learning. For instance, some studies used the framework as an analytical tool to identify the occurrence of the NOS aspects in science curricula (Erduran & Dagher, 2014b; Kaya & Erduran, 2016; Yeh, Erduran, & Tsu, 2019) and science textbooks (BouJaoude, Dagher, & Refai, 2017; McDonald, 2017) or to elicit teachers' views (Azninda, Raharjo, & Sunarti, 2021) and students' views (Akgun & Kaya, 2020) about NOS. Other studies used the framework as an instructional tool and tested the effectiveness of an RFN-based intervention on teachers' understandings of NOS (Cullinane, 2018; Erduran, Kaya, Cilekrenkli, Akgun, & Aksoz, 2020; Kaya, Erduran, Askoz, & Akgun, 2019). To our best knowledge, only two studies used the FRA as an analytical tool to explore scientists' views about NOS. The first study was conducted by Wu and Erduran (2022) to explore the NOS conceptions of Taiwanese scientists, and the second study (Peters-Burton, Erduran, & Dagher, 2023) was a reanalysis of previously obtained data from three groups of participants among which were scientists to understand their views about NOS from an FRA perspective. Henceforth, this study will extend the emerging literature on the FRA by exploring the NOS views of university science professors in the Lebanese context.

Purpose of the Study and Research Question

Building on the body of research on NOS just presented, the purpose of this study is to explore the conceptions of university science professors regarding NOS using the FRA framework in a different context, the Lebanese context. Specifically, the study aims to answer the following research question:

- What are the conceptions of university science professors regarding NOS, as envisioned in the family resemblance approach (FRA) in the Lebanese context?

Significance of the Study

The findings of the current study will contribute to theory by extending the literature on the FRA by exploring the NOS conceptions of university science professors in the Lebanese context. Adopting the FRA as the theoretical framework is of significance since it addresses the limitations of the previously used NOS frameworks which are narrow in scope, contain fewer categories, or are inclined towards one dimension. Another methodological significance is the use of a mixed-methods approach which is limited compared to the studies that either used quantitative or qualitative research methodologies to explore the NOS conceptions of scientists.

Concerning practice, this study is of significance since it will raise the professors' awareness about the importance of including aspects of NOS in their instruction, particularly aspects that belong to the social-institutional dimensions of science. These social aspects have the potential to attract more students to the scientific fields especially those who are not motivated by the cognitive aspects of science, thus promoting scientific literacy.

As for policy, the findings of the current study might motivate policy makers and curriculum developers to help science professors redesign their science curricula and textbooks and integrate more aspects of NOS in a meaningful and systematic way so that students end up having an authentic image of science.

CHAPTER 2

REVIEW OF LITERATURE

In this chapter, a review of the literature that motivated the current study will be presented. The data sources include published research articles in peer-reviewed journals, refereed books, and published dissertations. The first section introduces an area of research in science education known as nature of science (NOS) which is related to the epistemological understandings of science that are the nature of scientific knowledge, how it develops, and how scientists do their job followed by a brief historical overview about the different approaches towards conceptualizing NOS. The second section highlights previous studies done to explore the NOS conceptions of scientists who are the focus of the present study. The third section elaborates on a recent approach developed to conceptualize NOS, specifically the family resemblance approach or FRA, which is used as the theoretical framework of the study. The fourth section presents the empirical contributions of FRA in science education and concludes by addressing a gap in the existing literature on FRA thus providing a sound rationale for conducting this study.

Introduction

The rapid advancements in science and technology increasingly shape the world in which we live, a situation which necessitates educating citizens to become scientifically and technologically literate individuals (American Association for the Advancement of Science [AAAS], 1990, 1993; BouJaoude, 2002; National Research Council [NRC], 1996; Organization of Economic Cooperation and Development [OECD], 2017). Even though scientific literacy is an ill-defined phrase, there seems to be a general agreement that it entails "the public's understanding of science" (DeBoer, 2000, p.597), knowing what counts as science and how it differs from non-science, knowing the risks and benefits of science, using the scientific knowledge to make informed decisions about science-related issues, and thinking critically about science (Norris & Phillips, 2003). Yet, to achieve this goal, citizens should possess an adequate understanding of the nature of science (NOS) which is a critical component of scientific literacy (BouJaoude, 2002; Lederman, 2007).

Science educators, historians, philosophers, and sociologists of science provided several definitions to the construct "nature of science" (NOS) yet, "it most commonly refers to the epistemology of science, science as a way of knowing, and the values and beliefs inherent to scientific knowledge and its development" (Lederman, 1992). One of the proposed philosophical models to conceptualize NOS was the "consensus view". This view dominated the science education literature between 1990 and 2007 (Chang, Chang & Tseng, 2010). It was characterized by seven key aspects which are the following: (1) Scientific knowledge is empirical and thus is based on evidence, (2) Scientific knowledge is tentative and thus is subject to change, (3) Scientific knowledge is subjective which means that the same experimental data can be interpreted differently by different scientists based on their background, beliefs, and experiences, (4) Scientific knowledge is socially and culturally embedded, (5) Scientific knowledge involves creativity and imagination, (6) Distinction between observations and inferences and (7) Functions of and relationships between theories and laws. Additionally, this view opposes the scientific method myth which assumes that there is one single method that all scientists use to generate knowledge (Lederman, 2007; McComas, 2004). The aforementioned NOS list achieved wide agreement among researchers and science educators for its relevance to NOS teaching in K-12 classes. Moreover, it informed the development of a widely used instrument; the VNOS (Views of the Nature of Science) questionnaire to assess the degree of NOS understanding (Lederman, Abd-El-Khalick, Bell & Schwartz, 2002).

Despite this, the consensus view was challenged for several reasons. Some scholars critiqued it for being "universal" and argued for the move towards a "particularistic approach" of NOS in an attempt to help students appreciate the diversity that exists across and within the different scientific disciplines (Rudolph, 2000). Others argued that the consensus view ignores the role of model-building and advocated for engaging students in domain-specific scientific practices to enhance their science learning (Grandy & Duschl, 2007). Further critiques were also provided by Clough (2000) who suggested shifting the declarative statements about NOS into questions to promote discussion about NOS. As a result, several alternative NOS models emerged. For instance, Allchin (2011) argued for a "whole science" approach that considers elements, which are absent in the "consensus view" NOS list. He stated that:

> Whole science, like whole food, does not exclude essential ingredients. It supports healthier understanding. Metamorphically, educators must discourage a diet of highly processed, refined "school science". Short lists of NOS features should be recognized as inherently incomplete and insufficient for functional scientific literacy (Allchin, 2011, p.524).

As such, his approach considers reframing NOS from declarations to multiple dimensions unified by the theme of reliability such as the role of funding, cognitive biases as the role of prior beliefs, motivations for doing science, peer review, fraud as a form of misconduct, and the validation of new instruments and experimental practices.

Another model was provided by Matthews (2012) who called for a shift from NOS to "features of science" (FOS) in an attempt to broaden the scope of the nature of science beyond the epistemological focus on scientific knowledge. These features include values and socio-scientific issues, mathematization, technology, explanation, worldviews and religion, theory choice and rationality, feminism, as well as realism and constructivism.

More recently, Irzik and Nola (2011a, 2014) proposed the "family resemblance approach" (FRA) as an alternative framework to the "consensus view". Their framework is characterized by its comprehensive and systematic nature since it takes into consideration additional elements of science including its various epistemic, cognitive, and social aspects, which are either not addressed or partially addressed by the previous NOS models. Instead of having a chattered set of elements, FRA incorporates these elements under broader themes or categories which belong to either the cognitive-epistemic or the social-institutional systems. In a later work, Erduran and Dagher (2014) reconceptualized the philosophical FRA framework of Irzik and Nola (2011a, 2014) into a functional framework by providing a range of curricular, instructional, and assessment examples for science education purposes. They also expanded Irzik and Nola's framework (2014) by adding three categories under the social-institutional system of science to show how societal and cultural factors impact science and the work of scientists. Different terms were used to refer to Erduran and Dagher's FRA version such as extended-FRA, expanded-FRA, and "Reconceptualized FRA-to-NOS (RFN)" which was first used by Kaya and Erduran (2016, p.1118).

Despite the various definitions given to NOS, no one argues against its importance. Driver, Leach, Miller, and Scott (1996) provided five arguments to support the importance of having students learn and understand NOS. They are summarized as follows:

1. *Utilitarian:* Understanding NOS is necessary to make sense of science and manage the technological objects and processes in everyday life.
2. *Democratic:* Understanding NOS is necessary for informed decision-making on socio-scientific issues.
3. *Cultural:* Understanding NOS is necessary to appreciate the value of science as part of contemporary culture.
4. *Moral:* Understanding NOS helps develop an understanding of the norms of the scientific community that embody moral commitments that are of general value to society.
5. *Science learning:* Understanding NOS facilitates the learning of science subject matter.

However, for students to develop an adequate understanding of NOS, they need the assistance of teachers who are well-informed about NOS and can plan, and implement effective instructional strategies to accurately convey NOS aspects to students. As stated by Lederman (1992), “the most important variables that influence students’ beliefs about the nature of science are those specific instructional behaviors, activities, and decisions implemented within the context of a lesson” (p.351). The review of the literature on NOS continues to show that both teachers and students possess inadequate understandings of NOS. While the majority of the studies focused on exploring the NOS conceptions of K-12 students as well as pre- and in-service teachers, less attention was given to university science professors who are also referred to as “scientists” (BouJaoude & Santourian, 2010; Lederman, 2007; Lederman

&Lederman, 2014). Hence, this study will contribute to the limited literature in this area of research by exploring the NOS conceptions of university science professors. Given that these professors teach future scientists, science teachers of both elementary and high school levels, as well as individuals not majoring in science, then their role is crucial in presenting to students an adequate image of science and hence preparing them to become scientifically literate citizens. Therefore, understanding how university science professors perceive NOS is valuable. The following section reviews the findings of previous studies conducted with university science professors for the same purpose.

Research on Scientists' Conceptions of NOS

Previous research revealed that scientists hold mixed conceptions of NOS ranging from naïve (inadequate) to informed (adequate) NOS conceptions (Behnke, 1961; Pomeroy, 1993; Schwartz & Lederman, 2008). Some of the studies conducted with scientists compared their NOS views with those of teachers and students. For instance, Behnke (1961) compared the beliefs of high school science teachers and scientists about science. Data were collected using a fifty-item questionnaire which was developed around four categories: "nature of science", "science and society", "the scientist and society" as well as "the teaching of science". Participants were 621 teachers selected from the National Science Teachers Association's (NSTA's) membership list including 200 biology and 321 physical science teachers and 100 scientists selected from the Science Teaching Improvement Program of the American Association for the Advancement of Science and lists of well-known scientists in academia. Among the group of scientists, 52 were in the life science field, 48 were in physical sciences, 28 were interested in science education, and 72 were interested in research, academic life, and public affairs. The quantitative findings indicated that scientists and science teachers hold different views about science. These differences were evident the most in the "NOS" category which included items related to the value of team research, the limitations of science, the goals of scientific work, the scope of scientific approaches to everyday problems, and the tentativeness of scientific findings. The most-reported differences between the scientists and the teachers were those about the goals and limitations of science. For instance, 20% of scientists thought that the goal of scientific work is to improve human welfare, while 50% of science teachers thought otherwise. Moreover, 50% of the teachers and 20% of the scientists felt that scientific findings were not tentative. These differences were explained by a lack of understanding of NOS by both the teachers and the scientists. However, the scientists and the science teachers had similar views on items related to the "science and society", "the scientist and society", and "the teaching of science" categories. For instance, both groups were in strong agreement on the necessity of public understanding of science, and that scientists should be concerned with the social effects of their discoveries.

In another study, Kimball (1967-1968) explored the differences in the NOS understandings of qualified science teachers and professional scientists. Participants were 712 graduates from Stanford University and San Jose College out of which 625 had majored in science and 87 in philosophy. Data were collected using a 3-point Likert "Nature of Science Scale" (NOSS). The study reported that graduates who majored in science held inadequate understandings of science regardless of their years of experience or time since graduation. However, significant differences were evident when science majors were compared with philosophy majors who revealed more adequate understandings of NOS. Using a similar approach, Pomeroy (1993) explored differences in the NOS beliefs of scientists, secondary science, and elementary teachers.

Data were collected using a 50-item, 5-point Likert scale ranging from traditional Baconian views to non-traditional views of science and science teaching. This traditional view suggests that scientific knowledge cannot be questioned and that science aims to reveal factual truths about the world. The sample included 71 scientists and 109 teachers who were selected solely from the Alaskan cities. The results indicated that scientists hold more traditional views of science than all teachers combined.

Moreover, similar results were identified in local science education literature. For example, BouJaoude (1996) explored the differences in the epistemological and sociological beliefs of science among university science professors and students as well as high school teachers and students. Participants were selected from universities and schools in Lebanon in which English was the medium of science instruction. Data were collected using a 15-item questionnaire whose items were selected from three components of the VOSTS (Views on Science, Technology, and Society) inventory developed by Aikenhead and Ryan (1992). The results indicated that most of the participants held a traditional Baconian view of the epistemology and sociology of science.

In a more recent study, Elkhoury, BouJaoude, and Elhage (2014) explored the conceptions of university science professors about the epistemology of science. Participants were 24 professors from the faculty of sciences at a private Lebanese francophone university. Data were collected using a questionnaire and semi-structured interviews which were partially based on standardized questionnaires such as the VOSTS questionnaire and a modified version of the VNOS-C (Views of the Nature of Science) questionnaire developed by Lederman et al. (2002). The findings revealed that the science professors had mixed conceptions which are often naïve ones.

As can be seen from the studies reported above (Behnke,1961; BouJaoude, 1996; Elkhoury et al., 2014; Kimball, 1967-1968), scientists like teachers and students hold traditional views about science. As a result, these studies recommended the inclusion of philosophy and history of science in undergraduate science and teacher education programs.

Other studies compared the scientists' views of NOS based on their scientific disciplines and areas of research. For instance, Schwartz and Lederman (2008) explored the epistemological views that scientists hold regarding science as well as possible relationships between these views and the science context as the scientist's discipline or area of research. Participants were 24 scientists with an average of 25 years of experience representing four scientific disciplines (10 life science, 5 earth, and space science, 5 physics, and 4 chemistry) and four research approaches (10 experimental, 5 descriptive, 5 combination of experimental and descriptive, and 4 theoretical). Data were collected by using two open-ended questionnaires, the modified 9-item (VNOS-Sci) questionnaire developed by Lederman et al. (2002) and the 8-item scientist version of the Views of the Nature of Scientific Inquiry (VOSI-Sci) questionnaire developed by Schwartz, Lederman, and Thompson (2001) as well as semi-structured interviews. The results indicated (1) variations in the NOS views of scientists ranging across informed and naïve views, (2) NOS views of scientists did not differ according to the scientist's discipline or investigative approach, and (3) the consistency among the NOS aspects indicated that scientists have sophisticated epistemological (NOS) views.

Similar results were obtained in a study conducted by Bayir, Cakici, and Ertas (2014) to explore the similarities and differences in the NOS views of scientists concerning their major, whether natural or social sciences. Participants were 69 scientists from 5 disciplines in the natural and social sciences at a state university in the northwest of Turkey. Data were collected using face-to-face interviews based on the VNOS-Sci questionnaire (Lederman et al. 2002). All interviews were audiotaped, transcribed, and later analyzed using cognitive maps. The findings revealed that scientists have neither completely informed views nor completely naïve views about NOS, and scientists from both groups held similar views of NOS indicating that the scientists' views of NOS are not related to their scientific disciplines.

In a more recent study, Ssempala and Tillotson (2015) explored the conceptions of chemistry professors about NOS in a private-research university in the Northeastern United States. The participants were four chemistry professors teaching undergraduate and postgraduate chemistry courses. An ethnographic design was adopted and qualitative data were collected using in-depth/ open-ended individual interviews and classroom observations. The interview questions were based on the VNOS-Sci questionnaire targeting the seven aspects of the "*consensus view*" NOS list. All the qualitative data were transcribed verbatim afterward and then subjected to analysis. The results indicated that most of the chemistry professors hold positivist (traditional) conceptions of NOS. Henceforth, the study recommended that faculty members in the science education department share their research with colleagues in the science departments to improve the teaching and learning of science.

Additional studies investigated the NOS views of scientists together with the extent to which they incorporate NOS aspects in their instruction. For instance, Karakas (2009) explored how science professors teach science and NOS in their undergraduate introductory science courses. The participants were four instructors from a higher education institution in the Northeastern United States. The study followed an ethnographic design where qualitative data was collected using in-depth individual interviews with each professor as well as classroom observations. The interview questions were based on the VNOS-A, and C questionnaires developed by Lederman et al. (2002). The results indicated that:

- Professors preferred to use traditional teacher-centered lecturing as their teaching style and their main concern was to cover more content, develop the problem-solving skills of their students, and teach the fundamental principles of their subjects without giving special importance to the different NOS aspects.
- Professors considered variables such as large class size, lack of management and organizational skills, teaching experience, and instructors' concerns for students' abilities and motivation more important than teaching for the understanding of NOS.

The study recommended reducing the size of the introductory science classes to allow for the incorporation of NOS aspects during instruction and hiring instructors from the science education departments with appropriate undergraduate degrees to teach these introductory courses.

Along the same lines, Woitkowski and Wurmbach (2019) explored the NOS views of German physics professors and how frequently they address them in their physics classes. The participants were 50 physics professors from twenty different universities in Germany. Data were collected using a well-established 4- point Likert online survey based on previously administered German instruments which target certain aspects of NOS such as source and certainty of knowledge, development of knowledge, theories, and laws, scientific method, as well as creativity and imagination.

The survey included NOS scales and teaching scales developed in a way that higher scores indicate more adequate NOS views. The results of the study revealed that most of the professors hold adequate views of NOS except for two aspects which are the certainty of knowledge and scientific method hence showing the professors' adherence to naïve empiricism; a view that claims that scientific knowledge is based on evidence. Additionally, the professors seem aware of the importance of incorporating NOS aspects in their instruction which was also reflected in their teaching practices, yet, they considered some aspects to be more or less important.

To summarize, most of the studies reviewed were quantitative (Behnke, 1961; BouJaude,1996; Kimball, 1967-1968; Pomeroy, 1993; Woitkowski &Wurmbach, 2019) with few qualitative ones (Bayir et al., 2014; Karakas, 2008; Ssempala &Tillotson, 2015). As for the studies adopting a mixed-methods approach, they were also limited (Schwartz & Lederman, 2008; El Khoury et al., 2014). Additionally, the survey instruments used were mainly based on VNOS questionnaires which reflect a *consensus view* towards conceptualizing NOS. However, the "*consensus view"* with its fixed tenets (empiricism, tentativeness, subjectivity, creativity and imagination, social and cultural embeddedness, distinction between theories and laws as well as distinction between observations and inferences) was criticized for being narrow in scope. Consequently, the "*family resemblance approach*" (FRA) is chosen as the theoretical foundation of the current study. As discussed by Dagher and Erduran (2023), the FRA doesn't contradict the seven "*consensus view"* tenets, but rather takes into account additional NOS aspects that were not made explicit by the "*consensus view"* and articulates them in an interrelated, wholesome manner. A detailed description of the FRA framework is provided in the section below.

The Family Resemblance Approach

As previously mentioned, the "family resemblance approach" (FRA) was proposed by the philosophers Irzik and Nola (2011a, 2014) as an alternative to the "consensus view" and its limitations. The notion of "family resemblance" was originally used by Ludwig Wittgenstein (1958) to show that not all "words" can be defined using specific features. For example, as discussed by Irzik and Nola (2011a), the term "triangle" has certain defining features that make it a triangle such as three straight sides and being a closed plane figure, however, other terms like the word "game"; Wittgenstein's counterexample; cannot be defined similarly. This is because "games can be as different as ball games, stick games, card games, children's games that do not involve balls, sticks or cards (such as tag or hide-and-seek), solo games (hop-scotch), mind games, and the like" (Irzik & Nola,2011a, p.,594) and each game exhibits a set of characteristics that cannot be generalized to all kinds of games. A similar issue arises with attempts to define the term "science". Science involves various disciplines such as physics, biology, chemistry, zoology, botany, and astronomy, and it is hard to find specific characteristics that are only shared by all these scientific disciplines. To explain this further, Irzik and Nola (2014) provided the following disciplinary approach:

Let us represent data collection, inference making, experimentation, prediction, hypothetico-deductive testing, and blinded randomized trials as D, I, E, P, H, and T, respectively. Then we can summarize the situation for the disciplines we have considered as follows: Astronomy ={D,I,P,H}; Particle physics ={D,I,E,P,H}; Earthquake science={D,I,P′,H}; Medicine ={D,I,P″,E,T}, where P′ and P″ indicate differences in predictive power as indicated. Thus, none of the four disciplines has all the six characteristics, though they share a number of them in common. With respect to other characteristics, they partially overlap, like the members of closely related extended family. In short, taken altogether, they form a family resemblance. (p.1013)

Therefore, one of the strengths of the FRA is that it accommodates the domain-specific (distinct) and the domain-general (shared) characteristics of the different scientific disciplines, thus addressing the ongoing debates on demarcation issues.

Another strength of the FRA framework is its comprehensive and systematic nature that integrates the cognitive, epistemic, and social aspects of science in a coordinated manner. In their original FRA framework, Irzik and Nola (2011a) focused on the cognitive aspects of science represented in the four following categories:

1. Activities: these include the processes used in scientific inquiry like "observational practices" which vary according to the scientific discipline, "material practices" such as classifying objects, carrying out experiments, and calibrating instruments as well as "mathematical practices" which involve the use of mathematical skills (Irzik & Nola, 2011a, p.597).
2. Aims and values: involve making predictions, providing explanations, consistency, fruitfulness, simplicity, high confirmation, falsifiability, and empirical adequacy. These aims are based on the philosophical interpretations of science and they are considered cognitive values in the sense that the products of science are desired to fulfill them. Sometimes, these values function as criteria (methodological rule) for choosing a theory (Irzik & Nola, 2011a, p.597-598).
3. Methodologies and methodological rules: methodologies of science refer to the various reasoning strategies scientists use to produce reliable scientific

knowledge such as inductive, deductive, abductive, and hypothetico-deductive reasoning. As for the methodological rules, they guide the use of the different methods for example, "choose the theory that makes novel true predictions over the theory that merely predicts what is already known" and explain the self-corrective nature of science to eliminate its errors (Irzik & Nola, 2011a, p.598-600).

4. Products: are the products of the scientific activities which include, "theories, laws, models, collections of observational reports and experimental data" (Irzik & Nola, 2011a, p.600).

An additional category of social context which includes Merton's ethical norms, social values, and research ethics was introduced in a revised version (Irzik & Nola,2011b, as cited in Erduran and Dagher, 2014). In a later work, Irzik and Nola (2014) did slight modifications in naming three of the four categories that constitute the cognitive aspects of science where they replaced "Activities" with "Processes of inquiry"; to include in this category activities that are more familiar to science educators such as "posing questions (problems), making observations, collecting and classifying data, designing experiments, formulating hypotheses, constructing theories and models, comparing alternative theories and models" (p.1004); "Methodologies and methodological rules" by "Methods and methodological rules", and "Products" by "Scientific knowledge". Additionally, they elaborated on the fifth component of social context by transforming it into a social dimension including four categories. Following is a brief description of these categories.

1. Professional activities: include the various professional activities that scientists perform such as "attending academic meetings, presenting their

findings there, publishing them, reviewing manuscripts and grant proposals, writing research projects and seeking funds for them, doing consulting work for both public and private bodies and informing the public about matters of general interest" (Irzik & Nola, 2014, p. 1006).

2. Scientific ethos: these are the social and ethical norms that scientists should abide by while conducting their work or interacting with other scientists. They include Mertonian norms such as universalism, organized skepticism, disinterestedness, and communalism, in addition to other ethical norms which include: intellectual honesty, respect for the research subjects, respect for the environment, freedom, and openness (Irzik & Nola, 2014).
3. Social certification and dissemination of scientific knowledge: refers to the peer review process which acts as an "effective social quality control over and above the epistemic control mechanisms that include testing, evidential relations, and methodological consideration" (Irzik & Nola, 2014, p.1008).
4. Social values: include "freedom, respect for the environment, and social utility broadly understood to refer to improving people's health and quality of life as well as to contributing to economic development" (Irzik & Nola, 2014, p.1008).

The inclusion of the social-institutional aspects into the FRA framework helps communicate an authentic image of science and makes it appealing to a wider range of learners especially those who are not motivated by its cognitive aspects. An additional feature of the FRA framework is being a philosophically neutral model since it encompasses all NOS aspects discussed by other researchers except for the philosophical commitments proposed by Matthews (2012) in his “features of science” (FOS) model which are realism, feminism, and constructivism (Irzik & Nola, 2014).

Informed by their experience as science teachers and teacher educators as well as their expertise in the science education research field, Erduran and Dagher (2014, 2014a) adapted the theoretical framework of Irzik and Nola and transformed it in significant ways. One of the modifications done was shifting the sequence of the categories forming the FRA framework to start with “aims and values” since they believe that the aims and values of science are the determinants of its subsequent aspects. Another modification was substituting the terms “activities” and “processes of inquiry” with “scientific practices” due to its prominence in contemporary science reform documents in the USA including the Next Generation Science Standards (NGSS,2013) and A Framework for K-12 Science Education (NRC,2012), which also guide many curriculum reform efforts around the world. Besides the aforementioned modifications, Erduran and Dagher (2014) extended the original FRA framework to include three additional categories within the social-institutional dimension of science. A brief description of the additional categories is provided below.

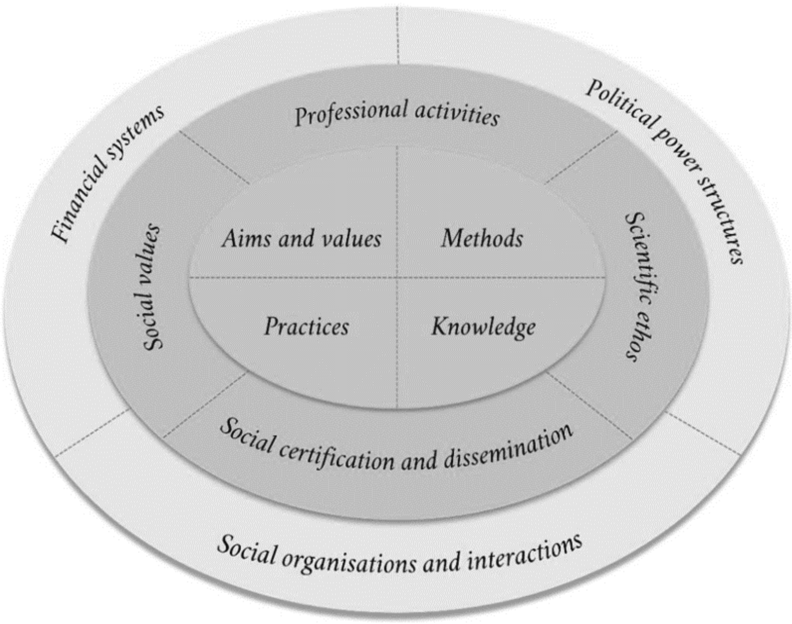
1. Social organizations and interactions: include the organizational structures and interactions among scientists working in and across different organizations (Erduran & Dagher, 2014, p. 145-146).
2. Political power structures: refer to the relationships between science and its political ends; including issues of gender and race among other factors; which might not always yield beneficial results (Erduran & Dagher, 2014, p.146-148).

3. Financial systems: Include issues of funding that are mediated by economic factors and which influence the distribution of resources in science as well as the nature of research conducted (Erduran & Dagher, 2014, p.148-150).

Additionally, Erduran and Dagher (2014) introduced visual representations known as the "Generative Images of Science" (GIS) to serve as heuristics (tools) for pedagogical and instructional implications in science education. Figure 1 shows the FRA wheel; one of the developed images; which illustrates the interplay between the various categories of science.

Figure 1

The FRA Wheel



Note. From "*Reconceptualizing Nature of Science for Science Education: Scientific Knowledge, Practices and other Family Categories*" 9p.28), by S. Erduran and Z. Dagher, 2014, Dordrecht, The Netherlands: Springer.

As shown in Figure 1, the FRA wheel is formed of three concentric circles. The innermost circle is formed of four quadrants representing the four categories of the cognitive-epistemic dimension. The larger concentric circle is also formed of four quadrants representing the four categories of the social-institutional dimension. And the outermost circle includes the three categories that were added to the social institutional dimension by Erduran and Dagher (2014). The lines between the circles and their compartments are porous indicating a constant interaction between the categories.

Empirical Contributions of FRA in science education

The FRA approach to NOS opened up new questions for research in science education. As a result, different empirical themes emerged all of which provide evidence about the framework's utility and effectiveness in improving the quality of science teaching and learning. These themes will be described in the sections that follow.

FRA in Curriculum Analysis

Erduran and Dagher (2014b) analyzed the coverage of NOS in a draft science curriculum and assessment specification for Junior Cycle (12 – 15 years) in Ireland using the FRA framework as the analytical tool. NOS was the unifying strand among all the science disciplines with an emphasis on the investigative, communicative, and social aspects of science. Although the results showed that the specification is consistent with recent trends in science education research, the NOS aspects included were presented in a disconnected fashion without being interrelated in meaningful contexts. The study recommended the use of the FRA framework increasing the depth and breadth of NOS content in the learning outcomes of the specification and supporting teachers in learning to teach and assess NOS.

In another study, Kaya and Erduran (2016) analyzed the content of two Turkish middle school science and technology curricula; abbreviated as MEB in Turkish;

published by the Ministry of National Education seven years apart (MEB 2013 and MEB 2006) using the RFN framework; which is an expanded version of the FRA; as the analytical tool. Furthermore, they used the international comparative analysis method to compare the curriculum documents across Turkey, the USA, and Ireland. Results showed that: (1) MEB 2013 covers more RFN categories than MEB 2006; (2) While both MEB2006 and MEB 2013 include categories that emphasize the cognitive-epistemic dimension of science, they underemphasize the social- institutional dimension of science; (3) While most of the RFN categories were present in the curriculum documents from Turkey, USA, and Ireland, yet they were presented in a disconnected manner rather than being coherent; and (4) The international curriculum documents show limited coverage of the categories of professional activities, financial systems, and political power structures. The study recommended the use of the FRA framework to guide revisions in the curriculum documents henceforth presenting the NOS in a holistic meaningful manner to students to aid in the quality of science teaching and learning.

Along the same lines, Yeh, Erduran, and Tsu (2019) investigated the coverage of NOS in two sets of Taiwanese curriculum guidelines published 10 years apart (MOE 2006 and NAER 2016) using the FRA as the analytical tool. Results showed a shift from the excessive centralization of the cognitive- epistemic dimension of science to a consideration of the social institutional system of science. The study recommends using the FRA framework as a guideline for curriculum revision to present the NOS aspects in an interconnected and holistic manner hence improving the quality of science learning and developing the students’ scientific literacy.

FRA in Textbook Analysis

BouJaoude, Dagher, and Refai (2017) explored the extent to which NOS content is portrayed in ninth-grade Lebanese science textbooks including the chemistry, life, and earth science as well as the physics textbook. The researchers used the FRA framework to analyze the NOS representations by applying it to the entire content of each textbook to avoid missing any NOS component and be mindful of contextual details. Their findings indicated that (1) None of the textbooks adequately addressed NOS; (2) The coverage of NOS components varied across disciplines. For instance, the physics textbook failed to address any of the 11 categories, while the chemistry textbook addressed four out of the 11 categories and the life and earth sciences textbook addressed five NOS categories; (3) The cognitive-epistemic categories of NOS were more frequently addressed in the life and earth sciences textbook (16 instances) than the chemistry textbook (5 instances) while the social institutional categories were similarly addressed in both textbooks with an emphasis on social values and neglect of the other five social categories. The study recommends the use of the FRA framework as a guideline to revise the coverage of the NOS content in the Lebanese science education goals and objectives and to better inform science textbook development by identifying areas where this content can be further strengthened.

In another study, McDonald (2017) explored the NOS representations in four Australian junior secondary school science textbooks within the topic of genetics for year 10 students. The researcher applied the FRA framework to identify the NOS aspects in the examined chapters including the topic, the key organizing sections (subtopics), science content (main narrative), historical and contemporary vignettes, science inquiry activities, and question sets. Results from this case-based analysis showed the presence of three explicit and numerous implicit aspects of NOS in the examined chapters. The study recommended that changes should be made to explicitly focus students' attention on the relevant NOS aspects within the content under study without addressing all the other NOS aspects.

Teachers' Views and Teacher Education Programs based on the FRA framework

In an attempt to elicit teachers' views about NOS based on the reconceptualized FRA framework (RFN), Azninda, Raharjo, and Sunarti (2021) collected data using the 70-item 5-point Likert RFN questionnaire together with individual interviews. Participants were 15 science teachers and 10 non-science ones. Even though the quantitative findings of the study indicated no significant differences in the mean RFN-Q scores between the two groups yet, qualitative results revealed differences in NOS views between the science and non-science teachers with better perceptions of the social institutional dimension of science among non-science teachers. Such differences can be explained in light of the teachers' learning experiences. That's why the incorporation of the history, philosophy, and sociology of science in courses that prepare prospective teachers is highly recommended.

While the aforementioned studies have shown how the FRA framework can be used as an analytical tool to analyze the occurrence of NOS aspects in curricula and textbooks and to understand how teachers view science, the FRA framework can also be adapted for pedagogical purposes. For instance, some studies tested the effectiveness of certain interventions on the teachers' understandings of NOS based on the FRA framework. Saribas and Ceyhan (2015) conducted an auto- ethnographic study to investigate the impact of using the Benzene Ring Heuristic (BRH) model on pre-service science teachers' (PSTs) understanding of scientific practices (SPs). The BRH is one of the visual tools developed by Erduran and Dagher (2014) in their FRA version of NOS. This heuristic was used in the study since it shows how the cognitive and epistemic aspects of science are interrelated and influenced by its social dimensions. Data were collected from various sources ***including*** pre and post-interviews, audiotape recordings of the lessons, students' lesson plans and reflections as well as reflections of the researcher and her colleagues after teaching. The results indicated that the use of the BRH was useful in improving the PSTs' understanding of SPs.

In another study, Kaya, Erduran, Askoz, and Akgun (2019) investigated the effectiveness of a 14-week teacher education intervention infusing RFN strategies through a series of workshops. Participants were 15 female preservice science teachers (PSTs') enrolled in a 4-year teaching education program in Turkey. Both quantitative and qualitative data were collected using the developed RFN questionnaire as well as pre- and post-intervention interviews with the individual preservice teachers. Results indicated an overall significant difference between the pre- and post-views of the PSTs' about the RFN, in favor of the post scores. This shows the impact of such intervention on PSTs views of NOS which in turn allowed them to relate the different dimensions of science to each other in a coherent manner.

Using a similar approach, Cullinane (2018) conducted a case study research design to investigate the impact of a teacher education intervention on Irish pre-service science teachers' (PSTs) understanding of NOS. The intervention was a series of workshops that were designed based on the FRA framework. Data were collected from different sources such as pre, post, and delayed post-survey data, audio recordings of the workshops, interviews, lesson observations, and lesson plans. The results indicated that the use of the FRA framework improved the PSTs' understandings of NOS, increased their confidence to teach NOS, and equipped them with the necessary skills to address NOS explicitly in their instruction.

In a more recent study, Erduran, Kaya, Cilekrenkli, Akgun, and Aksoz (2020) conducted an international comparative analysis to investigate the NOS perceptions of pre-service science teachers (PSTs) based on the FRA framework following group discussions in two different contexts: Turkey and England. Participants were 14 PSTs, 9 of whom were from Turkey and 5 from England. The group discussions were structured in two steps. In the first step, the participants were asked to reflect on NOS and record their key ideas on sticky notes, while in the second step, they were presented with the FRA wheel together with the definitions of its various categories, and they were asked to write their ideas on sticky notes and situate them on the wheel. A qualitative approach was used to analyze the verbal data collected from the group discussions. The findings revealed that both groups of PSTs initially emphasized the epistemic cognitive aspects of NOS and the introduction of the FRA wheel provided both groups with a more nuanced approach to conceptualizing NOS.

Students' Views of NOS based on the FRA framework

Akgun and Kaya (2020) investigated university students' perceptions of NOS based on the FRA framework. Participants were 15 university students from science and non-science majors enrolled in a public university in Turkey. Data were collected using the RFN questionnaire as well as in-depth individual interviews with the selected participants. The results indicated that (1) the NOS perceptions of the university students are linked to their disciplinary backgrounds. For instance, non-science majors illustrated a better perception of the RFN categories than the science majors; (2) university students were not explicitly aware of the different NOS aspects and their perceptions did not represent a holistic understanding of science. Hence, the study recommended revising the curriculum, especially for science majors using the RFN framework which allows the inclusion of the different aspects of the nature of science in a coherent meaningful manner to students.

Scientists' Views of NOS based on the FRA framework

Wu and Erduran (2022) investigated how scientists view NOS in general and from an FRA perspective in particular. Participants were 17 Taiwanese scientists (16 males and 1 female) whose ages ranged from 41 to 65 years old. Those scientists belonged to different disciplines (biology, earth science, chemistry, and physics) and were keen on science communication and outreach. Data were collected from five open-ended questions. To ensure equality, the participants were provided with brief definitions of the eleven FRA categories and a picture of the FRA wheel at the onset of the questions. The written responses were analyzed qualitatively (constant comparison method) and quantitatively (frequency count of the mentioned FRA themes). The results indicated that all the scientists' views were in line with the FRA framework since they detailed all its aspects about NOS. However, the social-institutional aspects were underrepresented in the scientists' depiction.

In a more recent study, Peters-Burton, Erduran, and Dagher (2023) reexamined data obtained from a previously conducted study by Peters-Burton and Baynard (2013) about the NOS views of three different groups of participants; involving middle school students (Grades 7 and 8), middle school teachers and scientists, using the FRA as the new theoretical approach. The statements identified from the participants' responses to four open-ended questions about the nature of knowing and the nature of knowledge were reclassified based on the FRA theoretical framework into their resultant FRA categories. Next, these statements were interpreted using the *epistemic network analysis* (ENA). The ENA involves grouping the qualitative statements into clusters of ideas, quantifying them by frequency counts, and then creating a network model to show connections among resultant ideas. The results revealed that among the three groups of participants, scientists mostly retained aspects about the FRA (81%), followed by students (68%) and then teachers (38%). Specifically, most of the categories related to the cognitive-epistemic FRA system were retained by scientists, while most of the categories related to the social-institutional FRA system were retained by students. Moreover, the resultant network models of scientists revealed evenly distributed connections around the FRA categories compared to those of students and teachers. This indicates that the scientists possessed coherent NOS views even though they didn't address all the FRA categories.

Conclusion

To conclude, the overview of the research literature on the FRA just presented provides sufficient evidence of the effectiveness of the framework in improving the quality of science teaching and learning. While the previous studies focused on curriculum analysis (Erduran & Dagher, 2014b; Kaya & Erduran, 2016; Yeh, et al., 2019), textbook analysis (BouJaoude et. al.,2017; McDonald, 2017), teacher education programs (Erduran et.al.,2018; Cullinane, 2018; Kaya et al., 2019; Saribas & Ceyhan,2015), teachers' conceptions (Azninda, Raharjo & Sunarti, 2021) as well as students' conceptions (Akgun & Kaya, 2020), only two studies analyzed the scientists' conceptions about NOS using the FRA as a theoretical framework (Peters-Burton, Erduran, & Dagher, 2023; Wu & Erduran, 2022). Therefore, the current study will make an empirical contribution by extending the emerging literature on the FRA through exploring the NOS conceptions of university science professors in the Lebanese context. Since university science professors have a pivotal role to play in the academic experiences of future citizens including those majoring in scientific or other non-scientific fields, then they have to have acceptable conceptions of NOS. Henceforth, this study will also contribute to practice by giving professors the chance to question the pedagogical techniques that they are implementing and drawing their attention to the importance of explicitly addressing NOS aspects in their instruction. Additionally, it will encourage policymakers and curriculum developers to support the professors in redesigning their science courses to include more aspects of NOS, thus attracting a wider range of students to the scientific domains and promoting scientific literacy.

CHAPTER 3

METHODOLOGY

Overview of Research Design

The purpose of this study is to explore the conceptions of university science professors regarding the nature of science (NOS). The evidence provided here will extend the emerging literature on NOS by exploring the NOS conceptions of university science professors in the Lebanese context using a recent theoretical framework; the "*family resemblance approach*" (FRA). FRA was developed by Irzik and Nola (2011a, 2011b, 2014) and later on, expanded by Erduran and Dagher (2014). Henceforth, this study is guided by the following research question:

- What are the conceptions of university science professors regarding the nature of science as conceptualized in the family resemblance approach (FRA) in the Lebanese context?

On this basis, the study lends itself to a mixed-methods design including the collection of both quantitative and qualitative data. Since the purpose of the study is to describe a current state of a phenomenon, which is the NOS conceptions of science professors, it will use a non-experimental descriptive research design of the survey type. Additionally, to elicit professors' in-depth NOS conceptions, then there is a need for a qualitative component, specifically conducting interviews with a purposefully selected number of science professors.

Participants

The participants for this study were scientists selected from a private university located in the area of Beirut-Lebanon in which English is the medium of instruction.

These scientists are university professors who earned a Ph.D. and have a professorial-academic rank at the university including assistant professors, associate professors, and full professors. They are experts in their fields and perform research in their related disciplines. The scope of this study is not only restricted to natural university science professors from the Faculty of Arts and Sciences (FAS) but rather, faculty members who teach science-technology and engineering-related subjects will also be included. This selection criterion is justified based on the emphasis on "*scientific and engineering practices*" as a major dimension in the recent science education reform documents (NRC, 2012). Moreover, it ensures a wide disciplinary sample of university science professors and targets the professors who teach future teachers in the aforementioned disciplines. As such, the university professors were selected from five faculties which are: the Faculty of Agricultural and Food Sciences (FAFS), Faculty of Arts and Sciences (FAS), Faculty of Medicine (FM), Faculty of Health Sciences (FHS), and Faculty of Engineering and Architecture (FEA).

Data Collection Tools

Data for this study were quantitative and qualitative, and the research instruments used were questionnaires and interviews. The quantitative component was derived from the "Reconceptualised Family Resemblance Approach to NOS" (RFN) questionnaire which was developed by Kaya, Erduran, Askoz, and Akgun (2019). The purpose of the questionnaire was to investigate the effect of an RFN-based teacher education intervention on pre-service teachers' (PSTs') understanding of the RFN categories. The RFN questionnaire is a 5-point Likert scale (Totally Disagree, Disagree, Not Sure, Agree, Totally Agree) consisting of 70 items that reflect the five RFN categories: "aims and values", "scientific practices", "scientific methods", "scientific knowledge”, and “social-institutional systems” as well as an additional category, “educational applications”. The “social institutional systems” category includes several subcategories such as “social values”, “political power structures”, and “financial systems”. The RFN questionnaire consists of both positive and negative items for each RFN category. For example, for the “aims and values” category, there are 7 items; 5 of the 7 items are positive (2, 20, 40, 51, and 69) and 2 are negative items (46 and 56). The use of negative items was justified based on reducing the acquiescence bias (agreement bias) where respondents tend to agree with the questionnaire statements regardless of their content. This kind of bias is considered a threat to the validity and reliability of survey instruments (Chyung, Barkin, & Shamsy, 2018). The internal consistency reliability of the questionnaire was calculated using Cronbach alpha and found to be acceptable ($\alpha = 0.8$). The participants can select one of the five given options to determine their views about each statement.

In this study, a modified version of the RFN questionnaire was used as the primary data-gathering instrument (see Appendix A). The modified version was developed following discussions with two experts in the field of science education, one of whom is the co-author of the expanded FRA. It was agreed that the positive item # 51 in the “aims and values” category which states that “Teaching epistemic, cognitive, social and cultural values should be the core components of the science curriculum”, and the negative item # 39 in the “social-institutional systems” category which states that “Intellectual honesty in science does not have to be taught in science lessons” (Kaya et al., 2019) be moved to the “educational applications” category since they are curriculum recommendations. Additionally, all the items of the “educational applications” category, which are sixteen in total, were excluded from the questionnaire since the purpose of this study is to explore the NOS conceptions of university science professors rather than how these professors consider the teaching aspects of RFN. However, it was recommended to include questions about the excluded category in the follow-up interviews especially since the study aims to draw the attention of these professors to the need to address the NOS aspects in their instruction. Henceforth, the modified questionnaire included 52 items in total. Table 1 summarizes the number of positive and negative items of each RFN category in the modified questionnaire. Moreover, to obtain a full description of the accessible population of professors, demographic items were added to the modified questionnaire such as items related to teaching experience.

Table 1

Positive and Negative Items in the Modified RFN Questionnaire

Name of the RFN Category	**Number of Items per RFN Category**	**Item Reference in the Questionnaire**	
		Positive	**Negative**
Aims and Values (AV)	6	1, 16, 30, 51	35, 42
Scientific Practices (SP)	13	3, 4, 12, 15, 18, 25, 29, 43, 46, 47	21, 39, 48
Scientific Knowledge (SK)	9	8, 23, 33, 38, 41	2, 13, 32, 49
Scientific Methods (SM)	9	9, 17, 19, 22	6, 20, 28, 37, 45
Social-Institutional Systems (SI)	15	5, 7, 11, 24, 26, 31, 34, 36, 40, 44, 50, 52	10, 14, 27

For the qualitative data, follow-up interviews were used as the primary data-gathering instruments to understand the meaning behind the professors' responses to the questionnaire items, and pursue in-depth information about their NOS conceptions as recommended by Lederman (1992). The follow-up interviews were of the semi-structured type in which the interviewer doesn't follow a standard list of questions but is free to reorder the questions, ask clarifying questions, and add or delete probes.

As for the interview questions, they were divided into three sets. The first set included theory-driven questions based on the FRA framework. The second set of questions requested elaborations on specific items in the modified questionnaire including item 6 (universal scientific method), item 7 (science as a social system), items 13 and 32 (forms of scientific knowledge), as well as items 18 and 25 (forms of scientific practices). The third set of questions targeted the "educational applications" category to explore how professors think about teaching the NOS aspects, and the extent to which they address them in their classrooms (see Appendix B).

Data Collection Procedures

Different procedures were used to collect the quantitative and qualitative data for this study. For the quantitative data, the Dean's Office of each faculty; FAS, FAFS, FM, FHS, and FEA were contacted to get the list of the faculty members' emails with whom the RFN questionnaire was shared. This procedure was done to confirm the emails in the obtained list with the professors' emails which are made publicly available on the university's website. The questionnaire was administered online using the Lime survey. The online questionnaire was sent to the two-hundred-forty-one participants identified above through an email. The cover page of the questionnaire explained the purpose of the research, requested consent to participate in the research, and informed potential participants that their participation in the research is voluntary. The cover page also included the contact information of the researcher. The estimated time to complete the questionnaire is between 20 and 30- minutes. Two weeks after emailing the questionnaire, a reminder thanking those who responded and encouraging others to do so was sent. Out of the two-hundred-forty-one invitations sent, only thirty-five complete responses were received. Responses to the questionnaire were anonymous unless the participants approved to be interviewed. Their approval was sought from a final YES/NO question added to the questionnaire items which asks the participants whether they would like to become potential interviewees. Participants who select the YES option were asked to provide their email addresses so that they can be contacted later. Eleven professors out of the thirty-five accepted to be interviewed including four professors from FAS (FAS-P5, FAS-P7, FAS-P12, and FAS-P13) two professors from FM (FM-P3 and FM-P4), two professors from FAFS (FAFS-P2 and FAFS-P4), two professors from FEA (FEA-P1 and FEA-P8), and one professor from FHS (FHS-P2). The interviews were conducted face-to-face in the professors' offices except for two, which were done virtually via Zoom. On average, the interviews took 22 minutes. An oral consent outlining the purpose of the research and confidentiality of data was obtained from the participants during the interviews and just before posing any questions. All the interviews were audio-recorded, transcribed verbatim afterward, and then subjected to analysis.

Data Analysis Procedures

The quantitative data collected were analyzed using the descriptive statistical-data analysis method. Therefore, to calculate the participants' scores from the questionnaire, a similar strategy to the one used by Kaya et al. (2019) will be adopted. First, the selection of the options for each item was coded. The options of 'totally agree', 'agree', 'not sure', 'disagree', and 'totally disagree' were coded as 5, 4, 3, 2, and 1, respectively. For the negative items, the codes of '5', '4', '2', and '1' were re-coded as ‘1’, ‘2’, ‘4’, and ‘5’, respectively. Recoding is a common approach in the interpretation of questionnaire data. Data were entered into SPSS to calculate the overall score for each participant. Following, the difference between the minimum and maximum total scores as well as the cut-off point between each category were computed. As a result, the obtained scores were divided into three ranges: lower third (traditional views), middle third (moderate views), and upper third (informed views). For each NOS category, the score interval, number, and percentage of professors holding the corresponding conceptions were determined.

For the qualitative data, the analysis of the transcribed interviews was done using the deductive coding approach (Linneberg & Korsgaard,2019) based on a coding frame (see Appendix C). The coding frame is composed of a list of pre-defined codes synthesized from the theoretical definitions of each FRA category as well as a set of indicative keywords relative to each category as provided by Erduran and Dagher (2014). First, segments of a text containing an idea (code) relevant to the research question were identified and labeled. Then, the identified codes were assigned to their corresponding FRA-category and corresponding FRA-system. Later, the analysis of the text segments was complemented with frequency counts to determine how often the participating professors referred to the FRA categories. Any emerging themes were also reported. It is important to note that the purpose of this study is to explore the views that university science professors hold about NOS, and not to judge them according to their views. Henceforth, the findings of this study would be relevant to compare the participants’ views with the past and contemporary views on NOS, and consider them entry points upon which the required NOS conceptions can be built.

Reliability

To ensure the reliability of the data collected from the follow-up interviews, the transcribed interviews, the coding process, and the resultant codes were reviewed by an expert in the science education field, who is the supervisor of this study. Following, a total agreement was sought in a meeting held with the supervisor to discuss the analysis and classification of the participants' responses into their corresponding FRA categories.

Limitations

This study meets many criteria of reliability and validity in research, yet it has some limitations which are worth considering in future studies. Since the university science professors were selected from the same university located in the area of Beirut, this might have influenced the findings of the study. Therefore, testing a more demographically representational sample is recommended to enhance the generalizability of the findings.

Another limitation stems from the sampling technique used which was on a volunteering basis. As a result, the participating professors who volunteered to participate in this study are not representative of other university science professors within their various disciplines. Therefore, the findings of the study cannot be generalized.

CHAPTER 4

RESULTS

In this chapter, the results obtained about the nature of science (NOS) conceptions of university science professors are reported in two sections. The first section presents the quantitative findings derived from the modified version of the RFN questionnaire. The second section reports the qualitative findings obtained from the semi-structured interviews.

Quantitative results

Presented in this section are the results of the university science professors' views of NOS. The results were obtained from the modified version of the "RFN Questionnaire", which was originally developed by Kaya, Erduran, Askoz, and Akgun (2019), and modified following discussions with two experts in the science education field, one of whom is the co-author of the expanded FRA. The modified "RFN questionnaire" is a 52-item and a 5-point Likert scale (Totally Disagree, Disagree, Not Sure, Agree, Totally Agree) reflecting the five RFN categories: "aims and values", "scientific practices", "scientific methods", "scientific knowledge", and "social-institutional systems" (see Appendix A). Additional demographic items related to the participants' gender, age, disciplinary area, highest degree earned, and total years of teaching experience were also included in the questionnaire.

Two-hundred-forty-one invitations were sent to the professors teaching science-technology-and-engineering related subjects from five faculties in the selected university including the Faculty of Arts and Sciences (FAS), Faculty of Medicine (FM), Faculty of Health Sciences (FHS), Faculty of Agricultural and Food Sciences (FAFS), and Faculty of Engineering and Architecture (FEA). Only thirty-five complete responses were received (Response Rate= 14.52%). Out of the 35 professors, 27 were males and 8 were females, which is representative of the professors' gender distribution at the chosen university, where male professors are a majority. The number of professors per faculty was as follows: thirteen professors from FAS, eight professors from FEA, seven professors from FM, five professors from FAFS, and two professors from FHS. A code was assigned for each participant which includes the abbreviation of the professors' corresponding faculty, the letter P, and a number count for each participant within the same faculty (e.g. FAS-P1).

A similar strategy to the one used by Kaya et al. (2019) was adopted to calculate the participants' scores from the questionnaire. Considering the positive items of the questionnaire, the options of 'totally agree', 'agree', 'not sure', 'disagree', and 'totally disagree' were coded as 5, 4, 3, 2, and 1, respectively. However, for the negative items, the codes of '5', '4', '2', and '1' were re-coded as '1', '2', '4', and '5', respectively. Afterward, the total score (which is the sum of the five RFN categories) was computed for each participant. The details of the participating science professors with their corresponding scores on the questionnaire are presented in Table 2.

Table 2

Demographic Data about the Participating Professors with their Corresponding Questionnaire Scores (N=35)

Faculty	Code	Gender	Age	Disciplinary Area	Highest Degree Earned	Total Years of Teaching Experience	Total RFN score
	FAS-P1	Male	50	Chemistry	PhD	19	199
	FAS-P2	Male	58	Natural Science	PhD	18	176
	FAS-P3	Female	58	Biology	PhD	26	184
	FAS-P4	Male	49	Biology	PhD	19	186
	FAS-P5	Female	41	Geosciences	PhD	10	183
	FAS-P6	Male	56	Natural Science	PhD	25	216
FAS	FAS-P7	Male	47	Environmental/Instrumental/ Chemistry	Habilitation	22	192
	FAS-P8	Male	57	Sciences/Chemistry	PhD	22	205
	FAS-P9	Male	36	Basic Science	PhD	7	220
	FAS-P10	Male	60	Chemistry	PhD	30	188
	FAS-P11	Male	47	Biology	PhD	15	186
	FAS-P12	Male	51	Biology	PhD	11	188
	FAS-P13	Male	57	Physics	PhD	25	201
	FM-P1	Male	61	Medicine	MD	29	188
FM	FM-P2	Male	42	Microbiology	PhD	13	203
	FM-P3	Female	59	Biochemistry & Molecular Genetics	PhD	23	200

Faculty	Code	Gender	Age	Disciplinary Area	Highest Degree Earned	Total Years of Teaching Experience	Total RFN score
	FM-P4	Male	78	Internal Medicine (Endocrinology) & Pharmacology	MD	50	186
	FM-P5	Female	41	Translational Research (Hematology /Oncology & Parasitology)	PhD	20	205
	FM-P6	Female	49	Medicine	PhD	15	189
	FM-P7	Female	51	Cancer Biology	PhD	14	197
FHS	FHS-P1	Male	62	Public Health	DrPH	30	185
	FHS-P2	Male	37	Medical Imaging	PhD	5	200
FAFS	FAFS-P1	Male	65	Food Science	PhD	33	210
	FAFS-P2	Male	76	Soil Science	PhD	44	189
	FAFS-P3	Male	65	Agriculture	PhD	35	188
	FAFS-P4	Male	59	Nutrition	PhD	33	187
	FAFS-P5	Female	45	Agriculture	PhD	6	180
FEA	FEA-P1	Male	45	Civil Engineering	PhD	14	212
	FEA-P2	Male	40	Engineering	PhD	11	200
	FEA-P3	Male	54	Engineering	PhD	20	197
	FEA-P4	Male	56	Architecture	Master	20	183
	FEA-P5	Male	56	Engineering	PhD	30	184
	FEA-P6	Male	44	Chemical Engineering	PhD	12	194
	FEA-P7	Male	49	Electrical & Computer Engineering	PhD	18	183
	FEA-P8	Female	33	Industrial Engineering	PhD	7	189

Then, based on the participants' minimum and maximum total scores on the "RFN questionnaire", the score intervals for each level of NOS understanding were determined in addition to the number and percentages of participants pertaining to each level. As can be seen from Table 1, the total scores on the modified "RFN questionnaire" ranged from 176 to 220 with a mean value of 193.51 rounded to 194 (SD=10.686). Since the difference between the maximum and minimum total scores was 44 points and the professor's NOS scores aggregated into three groups: lower third (traditional views), middle third (moderate views), and upper third (informed views), the cutoff point between each group is determined as 14.66 rounded to 15. The score intervals for each level of NOS understanding, in addition to the number and percentages of professors from each level, are reported in Table 3.

Table 3

Professors' NOS Views in terms of RFN Questionnaire Scores (N=35)

NOS conceptions	**Score interval**	**n**	**%**
Traditional	174-189 points	19	54.3
Moderate	190-205 points	12	34.3
Informed	206-221 points	4	11.4

Table 3 shows that 54.3% of the science professors hold traditional views of NOS, 34.3% hold moderate or mixed views and only 11.4% possessed informed views of NOS. Even though the results indicate that most of the university science professors hold traditional views of NOS, the minimum score (176) received is not considered a low score when compared to the normal range of scores implied by the modified RFN questionnaire (from 52 to 260). Moreover, if we divide this minimum score (176) by the number of questionnaire items (52), we get a moderate average score of 3.4 per item.

This means that the NOS views of the university science professors are relatively-traditional, leaning more towards being moderate. Nevertheless, we decided to keep the categorization especially that it agrees with previous literature on scientists' views about NOS (BouJaoude, 1996; Elkhoury, BouJaoude, & Elhage, 2014; Schwartz & Lederman, 2008; Woitkowski & Wurmbach, 2019).

In order to study the results more thoroughly, the distribution of the professors' NOS views was studied with respect to demographic variables including age, gender, total years of teaching experience, and faculty (disciplinary area). The distribution of the professors' NOS views in terms of their age and gender is reported in Table 3.

Table 4

The Distribution of Professors' NOS Views with respect to their Age and Gender

Variables	**Age**	**Gender**	
		Male n=27	*Female* n=8
Professors' NOS Views	Mean ± SD	%	%
Traditional	55.4±11	51.9	62.5
Moderate	48.3±7.5	33.3	37.5
Informed	50.5±12.7	14.8	0.0

As shown in Table 4, the professors having traditional views of NOS (n=19) have a mean age of 55.4 years (SD=11), professors having moderate views of NOS (n=12) have a mean age of 48.3 years (SD=7.5), while those with informed views of NOS (n=4) have a mean age of 50.5 years (SD=12.7). Concerning the professors' gender, the results show that out of the 27 male professors, the majority (51.9%) held traditional-NOS views, 33.3% held moderate-NOS views, and 14.8% held informed-NOS views. Likewise, out of the eight female professors, the majority (62.5%) held traditional-NOS views and all the rest (37.5%) held moderate-NOS views. Informed-

NOS conceptions were not reported among the participating female professors. Henceforth, it is hard to report any differences in the NOS views of the science professors based on their age and gender. Additionally, the distribution of the professors' NOS views in terms of their total years of teaching experience and the faculty to which they belong are reported in Table 5.

Table 5

The Distribution of Professors' NOS Views with respect to Years of Teaching and Discipline

Variables	**Total Years of Teaching Experience**	**Faculty by discipline**				
		FAS n=13	*FEA* n=8	*FM* n=7	*FAFS* n=5	*FHS* n=2
Professors' NOS Views	Mean ± SD	%	%	%	%	%
Traditional	23.5±12.2	53.8	50	42.9	80	50
Moderate	17.2±6	30.8	37.5	57.1	0.0	50
Informed	19.8±11.5	15.4	12.5	0.0	20	0.0

As shown in Table 5, the professors with traditional views of NOS (n=19) have an average teaching experience of 23.5 years (SD=12.2), professors with moderate views of NOS (n=12) have an average teaching experience of 17.2 years (SD= 6), while those with informed views of NOS (n=4) have an average teaching experience of 19.8 years (SD=11.5). Apparently, the results reveal that the total years of teaching experience have no effect on the professors' views about NOS.

Regarding the professor's faculty (disciplinary area), out of the thirteen professors in the FAS, 53.8% held traditional-NOS views, 30.8% held moderate-NOS views, and 15.4% held informed-NOS views. Similarly, in the FEA, half of the professors (50%) held traditional-NOS views, 37.5% held moderate-NOS views, and 12.5% held informed-NOS views. However, as for the seven professors from the FM, 57.1% held moderate-NOS views and the rest (42.9%) possessed traditional views. In the FAFS, 80% of the professors held traditional-NOS views and the rest (20%) held informed-NOS views. Finally, in the FHS, half of the professors (50%) held traditional-NOS views and the other half (50%) possessed moderate-NOS views. The results revealed an unsystematic distribution in the NOS views of the university science professors by their discipline. It can be concluded that there is no apparent relation between the professors' NOS views and their corresponding scientific disciplines.

Qualitative results

The following section presents the results of the qualitative data which aimed to provide an in-depth understanding of the science professors' views about NOS in general and from an FRA perspective in particular. According to Lederman, Abd-El-Khalick, Bell, and Schwartz (2002), interviews with 16% to 20% of the people surveyed are sufficient to validate their responses to the questionnaire survey. Fortunately, in this study, eleven professors (31.42%) out of the thirty-five surveyed accepted to be interviewed. All the interviews were audio recorded and then transcribed verbatim. Using the deductive-coding method, the transcribed interviews were analyzed in search of indicative text segments (codes). The resultant codes were compared against a coding frame that included the definitions as well as indicative keywords of the eleven FRA categories as described by Erduran and Dagher (2014). Henceforth, each code was assigned to its corresponding FRA category (Aims and Values-AV, Scientific Methods-SM, Scientific Practices-SP, Scientific Knowledge-SK, professional activities, scientific ethos, social certification and dissemination, social values, social organizations and interactions, political power structures, and financial systems), as well as the system to which it belongs whether cognitive-epistemic (CE) or social-institutional (SI).

Color codes were used to differentiate between the two systems where the blue color was used to designate the codes of the cognitive-epistemic system and the red color to designate the codes of the social-institutional system. Moreover, the green color was used to indicate a repeated code targeting the same meaning within the same identified category per response per participant, and the purple color was used to identify any emerging themes other than the eleven targeted FRA categories. Following this procedure, the frequency of occurrence of the FRA categories in the professors' responses was determined. The repeated codes were not counted. It is important to note that the code-identification process was guided by how the professors responded to each question. After finalizing the coding phase, all the coded transcripts were reviewed by an expert in the science education field to ensure the proper identification and assignment of each code with its corresponding FRA category. The following excerpt from a professor from the FEA illustrates the coding process.

> Science, we can define it in many different ways. You need to follow the scientific method, you need to have a hypothesis, you need to test it, you need to have evidence, data in-order to come up with certain models, certain rules in-order to establish a relationship between different variables in the world and you have different levels of course. That's a general description of science finding a relation between different variables in the world, in some way you need evidence, some data, experimentation in order to establish this. (FEA-P8)

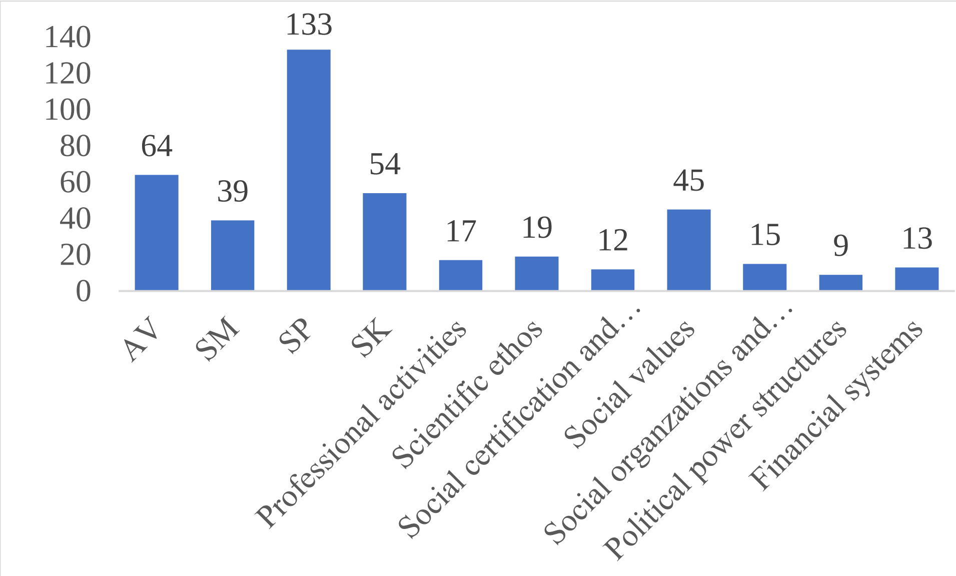
Even though the word scientific method was explicitly mentioned by the professor, yet based on the explanation provided, that professor was talking about the scientific practices involving the different processes of scientific inquiry such as you need to have a hypothesis, you need to have evidence. The provided excerpt was coded as follows: “You need to follow the scientific method”: (CE- SP: Process); “you need to have a hypothesis”: (CE- SP: Formulating hypothesis); “you need to test it”: (CE- SP: Experimentation); “you need to have evidence, data”: (CE- SP: Collecting data); “to come up with certain models, certain rules in-order to establish a relationship between different variables in the world”: (CE- SK: End products). Accordingly, this response resulted in 5 occurrences for the targeted FRA categories, all of which belong to the “scientific practices” category within the cognitive epistemic system. As for the code “finding a relation between different variables in the world, in some way you need evidence, some data, experimentation in order to establish this”, it was considered a repeated code since it is just repetition of the previously coded explanation, and hence was not counted. The coding process is explained thoroughly in Appendix D.

General Trends About FRA Categories in the Professors' Responses

A general overview of the frequency of occurrence of each FRA category as referenced by the eleven interviewed professors is provided in Figure 2. The frequency count of all the coded interview transcripts is provided in details in Appendix E.

Figure 2

Overview of the Results Showing the Frequency of Occurrence of each FRA Category in the Professors' Responses



Note. AV= Aims and Values; SM= Scientific Methods; SP= Scientific Practices; and SK= Scientific Knowledge.

Overall, the eleven FRA categories were addressed by the interviewed professors, who appear to be cognitively oriented especially since the three top frequency counts (133 for SP, 64 for AV, and 54 for SK) are for the categories within the cognitive-epistemic system. However, across the two systems, the results reveal that the "scientific practices" category is the most highlighted category (f=133) in the cognitive-epistemic system, and the "social values" is the most highlighted category in the social-institutional system (f=45).

Emerging themes

Notably, a new emerging category was identified in the responses of two professors. In one of the responses about what science is, a professor from the FM replied by saying: "**Science is** discoveries, **passion we should have passion for science"** (FM-P3). In another response about the influence of gender on doing science, a professor from the FAS replied as follows:

> Positively actually. I see it positive since I …. have come to realize that I am a backward thinker… So, I think that, also the intuition has a say, for instance how to set a hypothesis, **it's your feeling of your surrounding that makes you set a hypothesis**, while maybe other people need the data to set a hypothesis. I could have a hypothesis and go fetch the data because **I am in connection with my environment a lot, I feel it**, and because I collect a lot of data so at the end**, I am in connection with the spring that I am monitoring or the well** so this is where I but at the end everyone has to get to the point of data and to proving. (FAS-P5)

In the first excerpt, the professor explicitly described her feelings towards science as "passion". As for the second excerpt, even though the word "intuition" was mentioned, the professor reiterated the idea of possessing feelings in relation to the system under study (environment, spring, well). These feelings appear to be so entrenched to the extent that they guide the professor's cognitive practices, such as setting a hypothesis and collecting data. For this reason, the highlighted segments in the two excerpts were coded as themes related to "epistemic affect", which includes the various feelings that scientists experience when conducting their work (Jaber & Hammer, 2016).

Specific Trends About FRA categories across the five faculties

When the results obtained were examined more closely, variations in the distribution of the FRA categories across the five faculties were identified, which are illustrated in Table 6.

Table 6

The Frequency of Occurrence of Each NOS-FRA Category Across the Five Faculties.

		Faculty				
		FAS	**FEA**	**FHS**	**FM**	**FAFS**
	FRA Categories					
Cognitive-Epistemic System (CE)	**Aims and Values -AV**	29	9	4	11	11
	Scientific Methods-SM	18	3	3	5	9
	Scientific Practices-SP	67	18	8	18	22
	Scientific Knowledge-SK	25	5	4	9	11
Social-Institutional System (SI)	**Professional activities**	9	1	2	6	0
	Scientific ethos	7	4	2	4	2
	Social certification and dissemination of scientific knowledge	7	3	0	2	0
	Social values	22	8	1	6	8
	Social organizations and interactions	4	1	1	8	1
	Political power structures	6	0	0	3	0
	Financial systems	3	0	0	7	3

As shown in Table 6, the science professors in the FAS and FM addressed the eleven FRA categories (100%), however, professors in the other faculties referred to fewer FRA categories. More specifically, professors from the FEA addressed 9 of the 11 categories (82%) with no reference to “political power structures” and “financial systems”. On the other hand, professors from FAFS and FHS addressed 8 of the 11 categories (73%). While “professional activities”, “social certification and dissemination of scientific knowledge”, and “political power structures” were not addressed by professors from FAFS, “social certification and dissemination of scientific knowledge”, “political power structures” and “financial systems” were not mentioned by professors from FHS.

A Detailed Examination of the FRA-NOS Conceptions of University Science Professors as Revealed by the Interviews

Question Set 1. General Questions

The first question set was composed of three general questions targeting the FRA theoretical framework.

Definition of Science. The majority of the science professors (73%) revealed a cognitive-epistemic orientation when asked about the meaning of science. Following are some excerpts from their responses: “Mainly, a method to find robust explanations for observable phenomena.” (FAS-P12), “It’s an informed process” (FEA-P1), and “Traditionally, there is the scientific method where you would try to search and find information which is reproducible, which can be analyzed, which can lead to other similar information that will define how things operate, how things work” (FM-P4). On the other hand, 3 of the 11 professors (27%) addressed the social aspects of science while defining it. More specifically, they highlighted the “social values” category in the FRA framework and explained how science can improve people’s health and quality of life which is illustrated in the following excerpts: “Science is cure and practical solutions to problems and by science we need to save our planet and provide therapies for humans, improve the human race, and importantly to preserve our environment and our planet Earth” (FM-P3), and “Science is the work to understand what’s going around us and to be able to use it to make life or any process better.” (FAFS-P4)

Distinction between Science and Other Forms of Inquiry. In response to the second question on what distinguishes science from other forms of inquiry, the majority of the science professors based their justification on the “aims and values” category, where 9 out of the 11 professors (82%) emphasized the fundamental characteristics that science aims to satisfy as being imperative to distinguish it from other forms of inquiry. The most stressed items were empirical adequacy followed by objectivity and reproducibility which are illustrated in the following excerpts respectively: “the evidence-based nature of the data that makes it different from philosophy” (FEA-P8); “There’s no interference of personal ideas or anything” (FAFS-P2), and “in life there is a tendency with science to only accept what can be reproduced” (FM-P4). The second most highlighted justification was based on the “scientific practices”, where 8 of the 11 professors (73%) referenced the various strategies involved in scientific inquiry such as data collection, experimentation, and observations among others as essential characteristics of science. For example: “Probably it is what we call the scientific method, the fact that when we study something, or consider something, or try to look at the problem, we base our study on facts and observation” (FAS-P13), and “Science is more related to things that you discover, that you analyze, that you see with your own eyes.” (FHS-P2). On the other hand, 3 of the 11 professors (27%), referenced social aspects of science and emphasized the “scientific ethos” category; including the norms that scientists should abide by while conducting their work, as being distinctive features of science. For example, some professors stated that “aesthetics plays a big role in what idea is appealing to us and how we shape our ideas" (FAS-P12) and that "we need to be open-minded to accept any output" (FM-P3).

Social and Institutional Aspects of Science. When the professors were given the chance to discuss the social aspects of science, they provided rich explanations about the various social-institutional categories within the FRA framework. 10 out of the 11 professors (91%) mentioned the "social values" category with an emphasis on addressing societal needs and improving living conditions. Other categories of the social institutional system of the FRA framework were on average addressed by 2 out of the 11 professors (18%). These include "professional activities" as illustrated in the following excerpts: "when you patent" (FAS-P5), and "when we see on the internet some calls for research for application" (FAS-P7), "social certification and dissemination of scientific knowledge" cited in "peers are people working on similar subjects that you are working and therefore can evaluate whether your work is going to benefit the group or not and move science forward" (FM-P4), "social organizations and interactions" such as "science is going to be related to what the institution has objectives to work on, to guide its researchers, to do these kinds of things" (FHS-P2), "political power structures" affirmed in "if you look at science in Germany in the 30s right where there were lot of biologists who built a scientific framework for the racists ideology which we find now horrifying right?"(FAS-P12) and "financial systems" such as "I mean governments who have found the benefits of scientific discoveries OK had allocated a certain amount of funds a percentage of the tax collected to be spent on research" (FM-P4). The least referenced category was the "scientific ethos" which was voiced by only one professor as: "the umbrella under which you are doing your science where there is also ethics" (FAS-P5).

Question Set 2. Elaboration questions

The second question set was composed of elaboration questions by which the professors were asked to clarify their choices on specific questionnaire items. These questions can be grouped into four major themes:

Forms of Scientific Knowledge. Several professors stated that there is a hierarchical relationship between scientific theories and laws and that theories become laws with sufficient confirmation. For example, "Laws are higher-up, more verifiable" (FEA-P8), and "Laws…are actually theories that have been confirmed experimentally" (FAS-P13). Despite possessing this traditional hierarchical view, those professors were keen on communicating the idea that scientific knowledge is never absolute, rather it is subject to change as illustrated in this excerpt: "I would put laws on top of theories. Laws are when we have so many theories, it's well established you come up with a law. Theories, you test a theory…. There are no absolute laws…The biggest discoveries happened when the central dogmas were broken" (FM-P3).

As for scientific models, several professors identified them as tools rather than forms of scientific knowledge. For example, "Models help us understand the science but they are not knowledge per se" (FAS-P13), and "Scientific models are like the base…a template…a representative of a certain phenomenon" (FHS-P2). Another professor was able to capture the explanatory power of models when admitting that: "The sense of doing science is the sense of model building and you have to have a model to be able to make predictions…. in Biology I would say the prime example of model building is Mendel, Mendel's genetics" (FAS-P12). Moreover, the existence of different types of models was also addressed by one of the professors who explained it as follows:

It can be a process-based model where there are physics involved or math. It can be simple model as in and out and I am knowing what is happening inside so I am not able to understand the phenomenon itself but I understand how an out reacts to an in. And there is a third part which is a completely statistical model where I don't even try to reproduce what is happening inside. I am just looking at a certain inference of an output from an input based on pure statistics. (FAS-P5)

Universal Scientific Method. When the professors were asked to elaborate on the existence of a universal scientific method, they admitted the use of the traditional-standard scientific inquiry method while emphasizing experimentation to produce reliable knowledge. This is illustrated in the following excerpts: "The scientific method for me is about experimentation…you have to do the experiment, and then you have results, you assess these results and you try to improve and to optimize your experiment to improve more and more the result" (FAS-P7), and "I am an experimental scientist, the essence of science is observation and measurements and interpretation and in all four the basic sciences geology, physics, chemistry and biology observation, measurements, and analysis is common core to all of them" (FAS-P13)

Forms of Scientific Practices. The majority of the professors admitted that "observation" and "experimentation" are fundamental scientific practices across all scientific fields where they stated that: "A good scientist has to be a very good observer" (FAFS-P2), and "for me science is experimentation" (FAS-P7). Meanwhile, only one professor believed that in some cases observation doesn't apply, but other types of scientific practices such as inferences is required, as explained in: "we have the theoretical science…You use observations but you infer things that have happened in the past based on observations that are happening now. This is not direct observation this is indirect" (FAS-P5).

Science as a Social System. When asked to justify the description of science as a social system, the professors reflected on all the dimensions within this system as reported in question 1.3. Again, they emphasized the social utility of science as stated by one of the professors: "Everything that we are doing from models, experiments serve some purpose either improves quality of life, improves safety, efficiency, reduces cost in one way or another there has to be some practical application" (FEA-P8). However, when considering the "political power structures" dimension, the professors had contradictory views. While some professors addressed the view of non-subjectivity in science whereby factors like race, gender, and ethnicity don't affect its outcome, as evident in the following excerpts: **"**A scientist can be from any place in the world, any race that shouldn't affect the outcome" (FM-P3), and "I don't think that gender, race, ethnicity, whatever should have an influence on what you can do with science" (FEA-P8); others believed that science is subjective which they expressed as follows: "We see science as hard-core basic science as molecules interacting…but in our interpretation you can always sense the baggage that a person has carried over his/her lifetime and obviously gender makes a big difference" (FAS-P13), and "Everything that is part of the person of the scientist influences how they do science including the gender" (FAS-P12).

Furthermore, **s**ome professors acknowledged the interplay among the different dimensions within the social system where they discussed how the "financial systems" impact the scientists' "professional activities" within "social organizations". This was evident in the following excerpt:

> The university takes, when NIH or when the NSF funds, scientist cost includes salaries for people working (post-doctoral fellows, assistant professors, research assistants), lab facility, equipment, supplies and trips to attend conferences, costs of publication. This is the cost of a scientist, the investment that the NIH would put.(FM-P4)

Additionally, some professors highlighted openness as one of the important “ethos” guiding any scientific activity. For example, “In science you have to be open-minded” (FM-P3).

Question Set 3. Educational applications.

The third question set was about the educational utility of the FRA framework. It included the most questions especially that the items related to the “educational applications” category were omitted from the modified RFN questionnaire to be covered in the individual interviews.

Teaching Students about Scientific Aims and Values to Promote Scientific Literacy. All the professors acknowledged the importance of incorporating aspects of the “aims and values” of science in their teaching. From their responses, it appears that those professors integrate both epistemic-cognitive as well as social aims and values in their teaching practices. Considering the epistemic-cognitive aims and values, several professors emphasized empirical adequacy and reproducibility as illustrated in the following excerpts: “When I ask them to reproduce the experiment…they are aware that data should be accurate, data should be reproducible, otherwise we cannot say that these data are publishable or serve the causes” (FAS-P7). In terms of social norms and cultural values, the majority of the professors stressed scientific integrity and ethics as crucial aspects of any scientific activity. For example, “…when we do science as well it's like, we are dealing with integrity with some sort of scientific integrity" (FAS-P5), "In our PhD programs, we require ethics course but ethics is part of any teaching of any scientific inquiry (FM-P3). Moreover, some professors mentioned that the aim or value of science lies behind addressing societal needs as illustrated in the following excerpts: "Why are we looking for the next fastest most effective computer system or algorithms or way of treatment for a certain disease so…. if you understand the aims you may help in finding better solutions" (FEA-P1), and "how are you going to raise their motivation and make them interested in your topic if you don't explain what it is going to be used for" (FHS-P2).

Understanding the Scientific Methodology to Distinguish Science from Non-science. All the interviewed professors believed that understanding the scientific methodology helps students distinguish between science and non-science. Several professors pointed out that they communicate with students the view of a standard scientific method to generate evidence-based explanations, as illustrated in "when they see the methodology that we have used they will definitely be more convinced of what is really scientific what have passed the test of the scientific method" (FAS-P13), and "There are precise methods to follow in science." (FAFS-P2). One professor admitted the use of the other methodological forms including the historical dimension of science as illustrated in: "I teach biochemistry…for nursing and for graduate students, I always start my lecture, first lecture, by giving them the biggest discoveries in history. That would give them a feel…of the scientific advancements" (FM-P3). However, it was not clear whether the professor discusses with students how these historical data were obtained or how they relate to other existing scientific data.

Engaging Students in Discussions About Experimental Data. All the interviewed professors were aware of the importance of engaging students in discussions about experimental data and how science develops with time. Several professors reported that they stressed issues of reproducibility and validity in these discussions such as: “you have to determine uncertainty on this result, you have to reproduce this result and you cannot provide a result without an uncertainty” (FAS-P7). On the other hand, some professors referenced a variety of constraints that prevent them from running such discussions in the science classroom, and believed that these discussions are better done in seminars. They mentioned the constraints of time and curriculum as follows: “The problem is that often in our physics courses, the curriculum is so large….it doesn’t give us enough room to discuss these issues that are somehow seen outside of the curriculum” (FAS-P13), and “Not as much as I should… You look at your calendar and you see very little time slots available” (FEA-P1).

Integration of Social and Cultural Aspects of Science in Teaching. When asked about whether the science professors integrate social and cultural aspects of science in their teaching**,** the majority emphasized the use of real-life examples that are relevant to the material being taught. For example: “I teach Chemistry 202 which is Introduction to Environmental Chemistry for engineering students and you are talking about atmospheric pollution, about water pollution, water treatment, how to avoid atmospheric pollution etc…. I give them real examples, how these examples are affecting our life” (FAS-P7). Some professors claimed to have incorporated various social and cultural aspects of science in their teaching including social awareness, financial systems, political power structures such as gender, as well as social organizations and interactions. One of them claimed the following:

> I teach…plant nutrition and soil chemistry. I want my students to be able to design a fertilization program for different crops and then…the economics of it, of not only producing higher yield, is it economical to go to the highest yield? And then, livelihood of that producer, the farmer, and how much that farmer would make money out of it and from there how we go to food security. (FAFS-P2)

Similarly, another professor stated:

> If you look at the title civil and environmental engineering, social aspects are at the core of them so a lot of the things that we work on are driven by societal needs…The institutional…I may bring it in reference to how it affects the procedures we go through to design or to construct or whatever facilities that we are thinking of.(FEA-P1)

Summary of the results

In short, the quantitative research findings revealed that the surveyed university science professors hold mixed conceptions about NOS. Moreover, no relation was identified between the NOS conceptions of the professors and their age, gender, total years of teaching, or disciplinary area (faculty). As for the qualitative findings, the in-depth analysis of the transcribed interviews revealed that the professors' views about NOS were in line with the FRA framework since the eleven FRA categories were addressed by the interviewed professors to varying extents. While the categories of the cognitive-epistemic system were the most highlighted in the professors' responses, categories of the social-institutional system were underrepresented. However, this representation was unsystematic since the same professor who communicated a sophisticated understanding of some NOS aspects, held traditional-NOS views on other aspects. In that sense, it was hard to situate the professors' views into definitive levels (traditional, moderate, or informed). Therefore, their NOS conceptions were described as mixed conceptions, which is consistent with the quantitative findings. Besides that, no relation was identified between the professors' conceptions of NOS and their disciplinary areas, which is also consistent with the quantitative findings. Remarkably, a newly emerging theme; which was not previously reported in studies with scientists, was identified from the qualitative analysis results. This theme is related to "epistemic affect", an area that involves the affective experiences that occur for scientists while they engage in disciplinary work.

CHAPTER 5

DISCUSSION

This chapter is organized into four sections. The first section presents a summary of the main research findings and discusses them in reference to the literature on nature of science (NOS). The second section reviews the limitations of the study. The third section proposes recommendations for research, and the fourth section discusses implications for research and practice in light of the findings.

Discussion of the Results

In this section, the results of the study are discussed in reference to the relevant literature. This study aimed to explore the NOS conceptions of university science professors using the "family resemblance approach" (FRA) as the theoretical framework. For this purpose, a mixed-methods approach was used. First, quantitative data were collected from a 52-item- Likert scale questionnaire, which is a modified version of the original RFN questionnaire (Kaya, Erduran, Askoz, & Akgun, 2019). The modified questionnaire was administered to 241 university professors teaching science-engineering-and-technology related subjects in five different faculties (FAS, FAFS, FM, FHS, and FEA) at the chosen university. Thirty-five complete responses were received. Next, eight professors out of the thirty-five were interviewed to gain an in-depth understanding of their FRA-NOS conceptions. The transcribed interviews were coded deductively using a coding frame including the definitions as well as indicative keywords of each FRA category (Erduran & Dagher, 2014)

Generally, the descriptive-statistical analysis implied on the quantitative data, revealed that the university science professors held mixed views about NOS, the majority of which were traditional ones (54.3%). This finding is consistent with previous studies whose survey instruments were based on the *consensus view* of NOS (BouJaoude,1996; Elkhoury, BouJaoude, &Elhage, 2014; Ssempala & Tillotson, 2015), and reported that university science professors hold mixed NOS conceptions which are often traditional (naïve) ones. Additionally, the quantitative findings revealed that the NOS conceptions of the university science professors are not influenced by their disciplinary areas, which agrees with the findings of Schwartz and Lederman (2008) as well as Bayir, Cakici, and Ertas (2014).

On the other hand, the qualitative findings allowed for a better depiction of the NOS conceptions of the interviewed professors. These findings agree with Wu and Erduran (2022), in that the scientists addressed the eleven FRA categories while mainly focusing on the cognitive-epistemic aspects in reference to NOS. For instance, most professors described science as an empirical, testable, and experimental endeavor that exhibits a self-correcting nature. Additionally, the "scientific practices" and the "social values" were also identified as the most highlighted FRA categories. However, our findings are inconsistent with those reported by Perters-Burton, Erduran, and Dagher (2023), who identified only eight of the eleven categories in the scientists' responses while "social values", and the categories in the outer-most circle of the FRA wheel including "social organizations and interactions", "political power structures", and "financial systems" were excluded from their responses.

Even though all the FRA categories were discussed by the science professors in our study, the social-institutional FRA categories were underrepresented, which is consistent with other studies that also used the FRA as an analytical tool. For instance, studies that analyzed the occurrence of NOS aspects in curricula and textbooks across different contexts including Turkey (Kaya & Erduran, 2016), Lebanon (BouJaoude, Dagher, & Refai, 2017), Australia (McDonald, 2017), and Taiwan (Yeh, Erduran, & Tsu, 2019). Moreover, the science professors in our study were eager to talk about how science affects society and its growth, as well as the ethical principles that scientists should abide by when carrying out any scientific activity. They were also aware of their duty as a scientific community to convey scientific information to the public in a simplified, comprehensible manner. Despite this variability in the representation of the FRA categories, the interconnectedness within and across the eleven FRA categories was evident in the professors' responses to the interview questions. This finding is consistent with Peters-Burton, Erduran, and Dagher (2023) who revealed that scientists show coherent ideas in reference to the FRA categories.

Notably, one of the emerging themes in the findings of this study is "epistemic affect", which was echoed by two professors. According to Jaber and Hammer (2016), epistemic affect includes the various emotions, feelings, and dispositions that scientists experience in their epistemic pursuits. While one of the professors addressed epistemic affect by defining her feelings towards science as passion, the other professor explained how her feelings interact with cognitive experiences when she is engaged in doing science. These findings agree with the results of an ethnographic study conducted by Osbeck, Nersessian, Malone, and Newstetter (2011), which involved fifteen participants, including scientists, in two biomedical-engineering laboratories at a large research university. The analysis of interviews and observational data revealed an entanglement of the cognitive, affective, social, and cultural dimensions of scientific practice. These dimensions are considered part of science itself, and they drive persistence on tasks whether in professional or normal classroom settings (Davidson, Jaber, & Southerland, 2020). Accordingly, the emerging theme reported in this study is worth considering, especially that “care for motivation and affective dimensions of learning” is one of the principles that guided Erduran and Dagher’s conceptualization of NOS (Erduran & Dagher, 2014). Besides, “epistemic affect” is a new field that is gaining prominence in the science education literature. Currently, exploring the “affective experiences” of scientists remains understudied compared to the studies conducted with students and teachers for the same purpose (Davidson, Jaber, & Hammer, 2020; Jaber & Hammer, 2016).

While the science professors in this study revealed a sophisticated understanding of some NOS aspects, they still exhibited traditional views on other aspects. This complexity in their NOS conceptions agrees with Schwartz and Lederman (2008), Bayir et al. (2014), as well as Woitkowski and Wurmbach (2019) in that the NOS conceptions of scientists are neither completely informed nor completely naïve. This complexity in the professors’ views about NOS also agrees with the results of an analysis conducted by Gilbert and Mulkay (1984) on scientists’ discourse in a biomedical research area, who reported that scientists’ beliefs and actions in science do not follow a single pattern, rather they are diversified.

The existence of traditional views was linked to the hierarchical relationship between theories and laws, and as described by some professors the scientific theories become laws with frequent testing and sufficient time. Furthermore, most professors asserted the existence of a universal scientific method where they emphasized following a precise series of steps in any scientific activity. Finally, some of the professors did not recognize the subjectivity in science; rather, they believed that science is purely objective, reproducible, and unaffected by social and cultural factors like the gender, race, or ethnicity of the scientists.

In line with the FRA framework (Erduran & Dagher, 2014), sophisticated views about NOS were evident in the professors' responses. Considering the "scientific practices" category, some professors clearly distinguished between observations and inferences. Others acknowledged models as forms of scientific knowledge and discussed their different types. Additionally, some professors were aware of the subjectivity in science and explained the influence of various factors including gender on how science is done and interpreted.

It is important to note that having adequate views about NOS does not mean that these aspects are being transmitted effectively to students. As such, the findings of this study agree with Karakas (2009) who reported that some professors integrate the history of science in their instruction when they see it relevant. Similarly, most professors highlighted the use of real-life examples when asked about how they integrate social and cultural aspects of science in their teaching. By the same token, the participants mentioned several variables that might stand behind the explicit teaching about NOS including the large curriculum and its coverage in a limited time.

Limitations of the Study

The first limitation arises from selecting the university science professors from the same university, although they were professors teaching science-engineering-and-technology related subjects across five different faculties (FAS, FM, FAFS, FHS, and FEA) at the chosen university. Accordingly, increasing the sample size by including other universities can help ensure more representative results

Another limitation stems from the sampling technique used which was on a volunteering basis. As a result, the participating professors who volunteered to participate in this study are not representative of other university science professors within their various disciplines.

A third possible limitation is the small sample size used, where out of the two-hundred-forty-one invitations sent, only thirty-five professors volunteered to participate in the study.

Recommendations for Future Research

The study and the discussion above raise several interesting areas for future research. One proposed recommendation is to include classroom observations which can reveal additional details about the FRA-NOS conceptions of the participating professors, and the extent to which they incorporate these NOS aspects in their teaching practices. Another recommendation is to analyze the professors' discourse while doing their research to gain a better understanding of the variability existing in their corresponding FRA-NOS beliefs. A third recommendation is a need to explore the "affective experiences" of science professors; an understudied area in the science education literature, that can provide insights into the cultural diversity of science as advocated by the FRA framework. Finally, further studies are needed to understand how and where "epistemic affect" can be situated within the FRA framework.

Implications

This study has direct implications on the emerging literature on FRA and consequently has implications for practice and policy. Following is a discussion of the different implications.

Implications for theory

This study builds on calls for increasing empirical research on the utility of the FRA framework. It does so by exploring the NOS views of university science professors using the FRA in a different context; the Lebanese context.

Implications for methodology

Several limitations were identified in the previously conducted studies with scientists to explore their NOS views from an FRA perspective. While the two studies including Wu and Erduran (2022), and Peters-Burton, Erduran, and Dagher (2023) used open-ended questionnaires as data collection tools, this study addressed the limitations of using forced-choice questionnaires by complementing the professors' answers on the modified RFN questionnaire with follow-up interviews. Doing so helped reveal additional details about the NOS views of the participating science professors.

Implications for practice

Considering practice, this study gives professors the chance to question their pedagogical techniques and draws their attention to the importance of explicitly addressing NOS aspects in their instruction.

Implications for policy

The findings of this study advocate promoting collaboration and reflective dialogues between the professors in science education and professors teaching science-engineering-and-technology-related subjects in the five different faculties (FAS, FM, FAFS, FEA, and FHS) to help them redesign their science courses and include aspects of NOS in a meaningful, holistic manner. Moreover, it encourages university-led professional development programs to plan and implement FRA-based interventions that would help communicate the required understanding of the FRA approach and equip science professors with the necessary skills to explicitly address the FRA categories in their teaching. This will help improve the quality of science teaching and make it more accessible and more appealing to students even those not majoring in science, thus contributing to a scientifically literate society.

APPENDIX A
MODIFIED RFN QUESTIONNAIRE

Questionnaire Items	Totally Disagree	Disagree	Not sure	Agree	Totally Agree
1. Epistemic, cognitive and cultural values of science cannot be distinctly distinguished from each other.	☐	☐	☐	☐	☐
2. Scientific knowledge does not change.	☐	☐	☐	☐	☐
3. Scientists review and assess each other’s work.	☐	☐	☐	☐	☐
4. The power of experimentation comes from testing a scientific hypothesis many times by scientists.	☐	☐	☐	☐	☐
5. Science takes place in institutions such as universities and research centers.	☐	☐	☐	☐	☐
6. All scientific disciplines such as physics, biology and chemistry use the same scientific method.	☐	☐	☐	☐	☐
7. Science is a social system.	☐	☐	☐	☐	☐
8. Scientific progress occurs when ideas are evaluated and revised.	☐	☐	☐	☐	☐
9. Each branch of science has a different nature.	☐	☐	☐	☐	☐
10. Politics does not influence science.	☐	☐	☐	☐	☐
11. Scientists should respect the environment.	☐	☐	☐	☐	☐
12. Analysis and interpretation of data are components of scientific practices.	☐	☐	☐	☐	☐
13. Theories and laws are forms of scientific knowledge but models are not.	☐	☐	☐	☐	☐
14. Scientists don’t have to share their research with society.	☐	☐	☐	☐	☐

Questionnaire Items					
	Totally Disagree	**Disagree**	**Not sure**	**Agree**	**Totally Agree**
15. Scientists build and use models to understand complex scientific phenomena.	☐	☐	☐	☐	☐
16. The diversity of scientists solving a problem together means less biased results.	☐	☐	☐	☐	☐
17. There is no step-by-step order to doing science.	☐	☐	☐	☐	☐
18. All branches of science use observations.	☐	☐	☐	☐	☐
19. Diversity of methods contributes to scientific understanding.	☐	☐	☐	☐	☐
20. All hypothesis testing is manipulative.	☐	☐	☐	☐	☐
21. Some branches of science do not use representations.	☐	☐	☐	☐	☐
22. Scientists have to use different methods to produce enough evidence so that they can solve problems.	☐	☐	☐	☐	☐
23. Scientific knowledge consists of a coherent set of ideas.	☐	☐	☐	☐	☐
24. Scientists need money to do research.	☐	☐	☐	☐	☐
25. Classification helps scientists explain and predict phenomena.	☐	☐	☐	☐	☐
26. All scientific disciplines such as physics, biology and chemistry produce values that can contribute to society.	☐	☐	☐	☐	☐
27. The gender of scientists influences how they do science.	☐	☐	☐	☐	☐
28. There is a universal scientific method that all scientists use all over the world.	☐	☐	☐	☐	☐
29. Scientific experiments follow a certain set of procedures.	☐	☐	☐	☐	☐

Questionnaire Items	Totally Disagree	Disagree	Not sure	Agree	Totally Agree
30. Scientists should change their minds when they realize that their ideas are not supported by evidence.	☐	☐	☐	☐	☐
31. Policies of governments affect the growth of scientific knowledge.	☐	☐	☐	☐	☐
32. Laws are theories that are confirmed.	☐	☐	☐	☐	☐
33. Scientific models are tools to represent the real world.	☐	☐	☐	☐	☐
34. Some scientists earn more money than others, causing tension between scientists.	☐	☐	☐	☐	☐
35. Scientific facts are not affected by bias and individual subjective prejudices of scientists.	☐	☐	☐	☐	☐
36. Race and ethnicity of scientists have nothing to do with science.	☐	☐	☐	☐	☐
37. Changing variables is a fundamental requirement for a scientific study.	☐	☐	☐	☐	☐
38. Theories, laws and models work together to produce scientific knowledge.	☐	☐	☐	☐	☐
39. Different branches of science like physics, biology and chemistry have the same practices.	☐	☐	☐	☐	☐
40. Scientists write papers in academic journals.	☐	☐	☐	☐	☐
41. There are different kinds of theories. Some are accepted, others are still debated.	☐	☐	☐	☐	☐
42. There is no relationship between scientific facts and values.	☐	☐	☐	☐	☐
43. Scientists from all branches of science validate scientific knowledge by evaluating each other’s ideas.	☐	☐	☐	☐	☐

Questionnaire Items					
	Totally Disagree	**Disagree**	**Not sure**	**Agree**	**Totally Agree**
44. Scientists participate in conferences to share their research with other scientists.	☐	☐	☐	☐	☐
45. All scientific disciplines such as physics, biology and chemistry require constructing hypotheses.	☐	☐	☐	☐	☐
46. There are standards for evaluating the quality of scientific work.	☐	☐	☐	☐	☐
47. Models can help scientists to explain and predict phenomena.	☐	☐	☐	☐	☐
48. Scientific practices produce knowledge and are not influenced by cultural factors.	☐	☐	☐	☐	☐
49. Laws are more verifiable scientific knowledge than theories.	☐	☐	☐	☐	☐
50. There are social hierarchies among science teams and these can change.	☐	☐	☐	☐	☐
51. Scientific aims and values affect scientists' choice of methods in their investigations.	☐	☐	☐	☐	☐
52. Scientists socially interact with other scientists while doing research.	☐	☐	☐	☐	☐

Note. Adapted from Kaya, Erduran, Askoz, and Akgun, 2019

APPENDIX B
INTERVIEW QUESTIONS

Question Set 1: General questions driven by the FRA theoretical framework

1. What, in your view, is science? (Schwartz & Lederman, 2008)
2. What makes science or a scientific discipline (such as biology, physics etc.) different from other disciplines of inquiry (such as religion, philosophy, etc.)? (Schwartz & Lederman, 2008)
3. What comes to your mind when I say social and institutional aspects of science? Can you give any examples? (Akgun & Kaya, 2020)

Question Set 2: Elaboration questions

Participants will be asked to clarify their choices on the following questionnaire items: 6,7, (13-32), and (18-25)

Question Set 3: Educational Applications

1. Do you integrate social and cultural aspects of science in your teaching?
   a. If so, how often and for what purposes?
   b. If not, justify your choice?
2. Do you think that the science curriculum should not only cover scientific knowledge but also the social and cultural aspects of science? Justify your choice.
3. Do you think that teaching students about scientific aims and values improves their scientific literacy?
4. Do you think that it makes a difference to students' learning of science if they engage in discussions about experimental data, or how knowledge develops in science?
   a. If so, how often do you engage them in such discussions and for what purposes?
   b. If no, justify your choice.
5. Do you think that understanding scientific methodology can help students distinguish between science and non-science?

   (Questions 4 to 8 are based on the RFN questionnaire items of the "educational applications" category).

APPENDIX C
CODING FRAMEWORK

Cognitive-Epistemic System (CE)		
Name of the category	Definition	Indicative words
1. Aims and Values (AV)	Refer to the set of aims and cognitive values in the sense that the products of science are desired to fulfill them.	• Making predictions • Providing explanations • Consistency • Fruitfulness • Simplicity • High confirmation • Falsifiability • Empirical adequacy • Objectivity • Novelty • Accuracy
2. Scientific Methods (SM)	Include the various reasoning strategies that scientists use to produce reliable scientific knowledge.	• Inductive, deductive, abductive, and hypothetico-deductive reasoning. • Manipulation of variables
3. Scientific Practices (SP)	Include the diverse set of processes used in scientific inquiry	• Posing questions (problems) • Making predictions • Making observations • Collecting and classifying data • Designing experiments • Formulating hypothesis • Constructing theories and models • Comparing alternative theories and models

4. Scientific Knowledge (SK)	Refers to the products of the scientific activities.	• Laws • Theories • Models • Collections of observational reports and experimental data.
	Social- Institutional System (SI)	
1. Professional activities	Include the various professional activities that scientists perform.	• Attending academic meetings • Presenting findings • Publishing findings • Reviewing manuscripts and grant proposals • Writing research projects • Seeking funds • Doing consulting work for both private and public bodies • Informing the public about matters of general interest.
2. Scientific ethos	Include the social and ethical norms that scientists should abide with while conducting their work or interacting with other scientists.	• Intellectual honesty • Scientific ethics • Respect for and the protection of research subjects • Respect for colleagues and the environment • Freedom • Openness • Caution against bias • Mertonian norms which describe the ideal scientific community: Universalism: everyone can do science regardless of who they are Organized skepticism: objectivity, acceptance of scientific work should be conditional

		Disinterestedness: scientists should work only for the benefit of science Communalism: open science, ownership of scientific discoveries and publicly sharing them
3. Social certification and dissemination of scientific knowledge	Refers to the peer-review process	• Validation • Evaluation and criticism • Certification • Dissemination • Collaboration
4. Social values	Include freedom, respect for the environment, and social utility to improve people's health and quality of life as well as to contribute to economic development	• Culture • Society/ Social utility • Beliefs • Freedom • Respect
5. Social organizations and interactions	Include the organizational structures and interactions among scientists and relational transactions within and among scientific communities.	• University • Research center • Institution • Organization
6. Political power structures	Refer to the relationships between science and its political ends and who benefits from them.	• Gender • Ethnicity • Race • Nationality • Colonial interests • Ideological influences (Political beliefs as capitalism, socialism and Marxism)

7. Financial systems	Include issues of funding that are mediated by economic factors and which enable, control or limit the distribution of resources in science as well as the nature of the research conducted.	• Finance • Funding • Economy • Budget

Note. Adapted from Erduran & Dagher (2014); Wu & Erduran (2022)

APPENDIX D
QUALITATIVE DATA CODING

Table D 1

Qualitative Data Coding of Question Set 1

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
Q1: What, in your view, is science?	FAS	FAS-P5	Science OK it's anywhere were actually you have a hypothesis that you have to answer relating to any phenomenon around us at a small scale and at a large scale and when you start with the hypothesis you need to gather data through experiments or through measurements in order to come closer to either contradict the hypothesis or prove it. It requires most of the time some very tangible tools away from intuitions at least at the step where you are proving the hypothesis away from intuitions or speculations. For me science could be qualitative but it has to be as much quantitative as possible.	**(CE- SP: Formulating hypothesis):**you have a hypothesis that you have to answer relating to any phenomenon around us at a small scale and at a large scale. **(CE- SP: Collecting data):**you need to gather data **(CE- SP: Designing experiments):** experiments or through measurements **(CE- SM: Reasoning strategies):**either contradict the hypothesis or prove it **(CE- SP: Experimentation):**It requires most of the time some very tangible tools **(CE- SM: Reasoning strategies):** proving the hypothesis away from intuitions or speculations **(CE- SK: End products):**science could be qualitative but it has to be as much quantitative as possible.	
		FAS-P7	For me science is what we can do to improve living conditions of people in terms of environment, in terms of technology to help avoiding problems and finding solutions to	**(SI: Social Value):** science is what we can do to improve living conditions of people in terms of environment, in terms of technology to help avoiding problems and finding solutions to	**(SI-Social value/ Science for the society):** it's something that is for the whole society, the whole society without any exception.

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
			problems at all levels infant level, teenagers' level, adult level, female level, male level so it's really, it's something that is for the whole society, the whole society without any exception. So, science is here to help society and mainly applied science is the most important thing that we look forward. So many researchers work on sometimes theoretical science but unfortunately, they are not very well recognized because people love to see something that is implemented based on research that has been done in laboratories.	problems at all levels infant level, teenagers' level, adult level, female level, male level. **(SI: Social Value):**science is here to help society **(SI: Social Organizations and Interactions/Applied vs Theortical science)**:many researchers work on sometimes theoretical science but unfortunately, they are not very well recognized **(CE- SP: Designing experiments):**something that is implemented based on research that has been done in laboratories.	
		FAS-P12	What in my view is science. So, Ok. Mainly, a method to find robust explanations for observable phenomena.	**(CE- SP: Process):** a method **(CE- AV: Providing explanations):** find robust explanations **(CE- SP: Making observations):** observable phenomena.	
		FAS-P13	OK. For me science is what explains everything we see and we feel in this universe. That's my view of science	**(CE- AV: Providing explanations):** science is what explains everything we see and we feel in this universe.	
	FEA	FEA-P1	Woooh…Oh my gosh What is science? To me it's a process. It's an informed process.	**(CE- SP: Process):**It's an informed process.	

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
	FEA	FEA-P8	Science, we can define it in many different ways. You need to follow the scientific method, you need to have a hypothesis, you need to test it, you need to have evidence, data in-order to come up with certain models, certain rules in-order to establish a relationship between different variables in the world and you have different levels of course. That's a general description of science finding a relation between different variables in the world, in some way you need evidence, some data, experimentation in order to establish this.	**(CE- SP: Process):** You need to follow the scientific method. **(CE- SP: Formulating hypothesis):** you need to have a hypothesis **(CE- SP: Experimentation):** you need to test it **(CE- SP: Collecting data):** you need to have evidence, data **(CE- SK: End products):** to come up with certain models, certain rules in-order to establish a relationship between different variables in the world	**CE-SK: End products:** finding a relation between different variables in the world) in some way **CE- SP:Collecting data:** you need evidence, some data, **CE-SP: Designing experiments:** experimentation in order to establish this.
	FHS	FHS-P2	Science, everything is science in fact whether its literature, its living things, dead things. Everything is could be related to, to science. What exactly are you looking at? ***It's a general question.*** For me, in my domain, science is the study of the living let's say. It's the study of how things work, how things work. That's it	**(CE- SK: End products):** everything is science in fact whether its literature, its living things, dead things. **(CE- SP: Process):** science is the study of the living **(CE- SP: Process)**: the study of how things work	
	FM	FM-P3	Science is discoveries, **passion we should have passion for science** and for me science is cure and practical solutions to problems and by science we need to save our planet and provide therapies for humans, improve the human race, and importantly to preserve our environment and our planet Earth.	**(CE- SP: Process):** Science is discoveries **(SI- Social Value):** science is cure and practical solutions to problems **(SI- Social Value):** by science we need to save our planet	**(Emerging theme- passion): we should have passion for science** **Repitition: Do I count it?** **(SI: Social Value/ Science being a cure):** provide therapies for humans, improve the human race), and importantly **(SI: Social Value/Science to save our planet):** to preserve our environment and our planet Earth)

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
		FM-P4	I responded I think to this question. Traditionally, there is the scientific method where you would try to search and find information which is reproducible, which can be analyzed, which can lead to other similar information that will define how things operate, how things work. Ok. This is very general primitive definition of science and it covers all fields.	**(CE- SP: Process):**there is the scientific method **(CE- SP: Collecting data):**search **(CE- SK: End products):**find information **(CE- AV: Accuracy):**reproducible **(CE- SM: Reasoning strategies):**can be analyzed **(CE- SK: End products):**can lead to other similar information that will define how things operate	
	FAFS	FAFS-P2	What in my view is science? Ok. I told you don't ask us complicated questions. Well, it's observation and experimentation and after that obtaining results and building conclusions on results that are obtained. Of course, there are some speculations but we have to obtain results on facts that we collect data.	**(CE- SP: Making observations):**it's observation **(CE- SP: Designing experiments):**experimentation **(CE- SK: End products):**obtaining results and building conclusions on results **(CE- SP: Making predictions):**some speculations	(**CE- SP:End products**): but we have to obtain results on facts that **(CE- SP:Collecting data)**:we collect data.
		FAFS-P4	Science is the work to understand what's going around us and to be able to use it to make life or any process better.	**(CE- SP: Process):** the work to understand what's going around us **(SI- Social value):** to use it to make life or any process better.	

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
Q2: What makes science different from other disciplines of inquiry (such as religion, philosophy, etc.)?	FAS	FAS-P5	Definitely, you have the chance to have more consensus over things because you are proving it with actual data and in places where data do not exist you can prove it through governing equations definitely with time, we have proven that things can be wrong even if we have used some commonly known rules or theorems but most of the time you can actually contradict it by looking at the data and what comes out of it. It is the scientific model that does not exist in other such as religion which is based more into intuitive approaches or things that you cannot prove.	**(CE- AV: Consistency and accuracy):**the chance to have more consensus over things **(CE-SM: Reasoning strategies):** proving it with **(CE- SP: Collecting data):**actual data **(CE- SK: End products):**through governing equations **(CE- AV: Falsifiability):**we have proven that things can be wrong even if we have **(CE- SK: End products):**used some commonly known rules or theorems **(CE- SP: Process):**It is the scientific model that does not exist in other	
		FAS-P7	Okay. Yaa, your question is so I believe the answer is straight forward. When we talk chemistry, biology, etc. so we talk math, we talk numbers, and as you know one plus one equals two so there is no philosophical approach to let's say, we might predict some results in the lab but these predictions still not proved unless you do the experiment so you wait for results, you assess these results based on experiment and you check if these results are coherent with the theory that we learned and we teach in our labs for our students.	**(CE- AV: Empirical adequacy):**When we talk chemistry, biology, etc. so we talk math, we talk numbers, and as you know one plus one equals two **(CE- SP: Making predictions):** we might predict some results in the lab **(CE- SP: Experimentation):** you do the experiment **(CE- SM: Reasoning strategies):** you assess these results based on experiment **(CE-SK: Products of the scientific activity):** you check if these results are coherent with the theory	

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
		FAS-P12	So, in science there is the attempt to, the attempt to, that the collective endeavor is objective that doesn't mean that the individual scientist is objective but the collective endeavor is independent, so that means you know reproducibility, so anybody regardless of their own biases, life experiences and so on can reproduce a particular outcome, and all this means, I always see it as you know nature being the ultimate judge right or the you know, our disciplines I guess have already other aspects of human thinking so for example aesthetics play a big role in what idea is appealing to us and how we shape our ideas but we have something outside of us that always tell us overtime whether or not we are right. We have data outside of our mind that tells us whether or not we are right. And I think in other disciplines there is no outside judge like nature. They are sort of competing ideas and maybe there is the collective of the discipline but there is not this the data that ultimately come from the underlying mechanisms that we try to uncover that in the end tells any scientist whether or not they are right. So, I feel like when I compare our discipline to other disciplines, this nature being the outside judge is missing in most of the humanities	**(CE- AV: Objectivity):** the collective endeavor is objective **(CE- AV: Reproducibility):**you know reproducibility **(CE- SP: Observations and data collection):** you know nature being the ultimate judge **(SI- Scientific ethos/ esthtics: principles guiding the scientific activity):** our disciplines have already other aspects of human thinking for example aesthetics play a big role in what idea is appealing to us and how we shape our ideas **(CE- SM: Reasoning strategies):** we have something outside of us that always tell us overtime whether or not we are right. **(CE- SK: End products):** the data that ultimately come **(CE-SP: meachanisms/scientific activities):** from the underlying mechanisms that we try to uncover in the end **(CE- AV: Empirical adequacy):** tells any scientist whether or not they are right.	**(CE-AV: Objectivity/ Reproducibility):** anybody regardless of their own biases, life experiences and so on can reproduce a particular outcome **(CE- SM: Reasoning strategies)**We have data outside of our mind that tells us whether or not we are right. **(CE- SP: Observations and data collection)**when I compare our discipline to other disciplines, this nature being the outside judge is missing in most of the humanities

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
		FAS-P13	OK. Probably it is what we call the scientific method The fact that when we study something, or consider something, or try to look at the problem, we base our study on facts and observation.	**(CE- SP: Process):** it is what we call the scientific method **(CE- SP: Observations and data collection):** when we study something we base our study on facts and observation	
	FEA	FEA-P1	Ahhh Another very tough question. Ahhh The issue is I don't know a lot about those other sciences but I feel more comfortable talking about the STEM the English, Science, Engineering. I think the process is a bit more, a bit more defined, a bit more ahhhh detailed in a way that could be just because I am more familiar with it meaning ahhh I've never done studies in philosophy or religion or history or anything like that it's a bit of a black box for me but I feel just as an outsider I feel that our processes in engineering and science and so on are a bit more defined. Now you ask me why? I don't know maybe because there is so much level of work in them the level of advancement in them is so high because of the needs they tend to have a lot of traffic so they get sharpened they get advanced at a much faster pace than some of the other fields.	**(CE- SP: Process):** I think the process is a bit more defined **(SI: Social Value):** the level of advancement in them is so high because of the needs **(CE- AV: High confirmation):** they get sharpened they get advanced at a much faster pace than some of the other fields.	**(CE- SP: Process):** our processes in engineering and science and so on are a bit more defined.
	FEA	FEA-P8	I think actually the evidence-based nature of the data that makes it different from philosophy just the fact that you have to do experiments, you have to collect data, so its evidence based.	**(CE- AV: Accuracy/ High confirmation):** the evidence-based nature of the data that makes it different from philosophy **(CE- SP: Designing experiments):** you have to do experiments **(CE- SP: Data collection):** you have to collect data	**(CE- AV: Accuracy/ High confirmation):** so its evidence based

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
	FHS	FHS-P2	First thing first it's they are based on facts, they are factual you need facts to call them let's say scientific whether, whereas religious and the ones that you have cited are more based on faith, on hearsay, on written documents. Science is more related to things that you discover, that you analyze, that you see with your own eyes.	**(CE-SP: Making Observations):** they are based on facts **(CE-SM: Reasoning strategies):** science is more related to things that you discover, that you analyze **(CE-SP: Making Observations):** you see with your own eyes.	**(CE-SP: Making Observations):** they are factual you need facts to call them let's say scientific
	FM	FM-P3	Science you need a hypothesis, then you do experiments, you have to test your hypothesis and its evidence based and at the end either you accept your hypothesis or you refute it. There is nothing that we are sure about 100 % we need to test it and we need evidence and we need to be open minded to accept any output. Even if you have faith you have to prove it in science.	**(CE- SP: Formulating hypothesis):** Science you need a hypothesis **(CE- SP: Designing experiments):** you do experiments **(CE- AV: Accuracy/High confirmation):** its evidence based **(CE-SM: Reasoning strategies):** at the end either you accept your hypothesis or you refute it. **(SI- Scientific ethos: Openness):** we need to be open minded to accept any output.	**(CE- AV: Accuracy/ High confirmation):** we need to test it and we need evidence **(CE- AV: Accuracy/ High confirmation):** you have to prove it in science.
		FM-P4	In basic principle nothing. In reality, in life there is a tendency with science to only accept what can be reproduced and what can be seen, demonstrated by experiment, by whatever. In religion there are areas where you will never be able to move forward but you still accept, تؤمن بالغيب, you have to believe it's not a matter of proving the existence or lack of existence of الغيب, it is. That's where we are we can't go further and that is why there is a; Now in science and math there is conjecture there is but then you have to prove it. And this goes even to philosophy to keep checking whether this is	**(CE- AV: Reproducibility/High confirmation):** in life there is a tendency with science to only accept what can be reproduced **(CE-SP: Making Observations):** what can be seen **(CE- SP: Designing experiments):** demonstrated by experiment **(CE-SP: Making Predictions):** Now in science and math there is conjecture there is **(CE-AV: Empirical adequacy):** but then you have to prove it.	

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
			what is existing what is occurring what you've described, describes situations whereas in religion there is there are a quite bit of areas where, that is it, you either you want it or you don't want it, you believe in it, you accept it or you don't accept it.		
	FAFS	FAFS-P2	Because it depends on things that you feel, you know, you touch. It is not theoretical. It is hand-on information. You receive information either in the lab or in the field or anything and then you collect data and you build your results, you build your conclusion on the data It is not emotional. It doesn't depend on how you would like to see it. There's no interference of personal ideas or anything. It depends on data, interpretations.	**(CE-SP: Making Observations):** It depends on things that you feel, you know, you touch **(CE- SP: Designing experiments):** It is hand-on information **(CE- SP: Scientific activities):** You receive information either in the lab or in the field **(CE-SP: Data Collection):** you collect data **(CE-SM: Reasoning strategies):** you build your results **(CE-AV: Objectivity):**There's no interference of personal ideas or anything	**(CE-SM: Reasoning strategies):** you build your conclusion on the data **(CE-SP: Data Collection):** It depends on data **(CE-SM: Reasoning strategies):** interpretations.
		FAFS-P4	Science is supposed to be based on fact, you know relatively or to a large extent on facts. Now religion is the belief. There is no evidence you know, you believe in something, you could believe in anything. Science you do have more of evidence in a way and it seems that both of them are needed for human for some reason.	**(CE- SP: Making observations):** Science is supposed to be based on fact, you know relatively or to a large extent on facts. **(CE-AV: Accuracy/High confirmation):** Science you do have more of evidence	
Q3: What comes to your mind when I say social and institutional	FAS	FAS-P5	OK. Social is where a group of people influence the need to research a certain topic in science. This is the only place where social can influence science. Why am I doing this scientific; why am I looking at this scientific inquiry. As for institutional, it is the entire framework in which	**(SI: Social organizations and interactions):** Social is where a group of people influence the need to research a certain topic in science. **(SI: Social organizations and interactions):** it is the entire framework in which you look for science including logistical approaches	

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
aspects of science?			you look for science including logistical approaches and the umbrella under which; when you patent; the umbrella under which you are doing your science where there is also ethics. My opinion is that it is institutional, it has been institutionalized but it is something that goes beyond institutions. There is a proportion of science that you cannot put under these two. I see it that way. Maybe you can help me if there is something that I have omitted.	**(SI: Professional activities):** when you patent **(SI: Scientific ethos):** there is also ethics. **(SI: Social values):** it is something that goes beyond institutions	
		FAS-P7	Social and institutional. In our days of course social is something that is penetrating science actually, the real science. Because as I have said before starting the implementation of applied science so if applied science is implemented without a society so there is no sense for this applied science or for the science to be done in the labs so that's why social is very important and diversity which means when we let's say when we see on the internet some calls for research for application etc., we understand that there is a need, some need. This need might be a social need but all needs are social by the way they are social needs for this that's why they are very close very close and they converge into one objective is to help the society to feel better, live better, to be more healthy etc. etc.	**(SI: Social values):** if applied science is implemented without a society so there is no sense for this applied science **(CE-SP: Experimentation):** for the science to be done in the labs **(SI: Professional activities):** when we see on the internet some calls for research for application **(SI: Social values):** we understand that there is a need, some need. This need might be a social need **(SI: Social values):** they converge into one objective is to help the society to feel better, live better, to be more healthy	

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
		FAS-P12	So, you mean examples of how social and institutional aspects shape the direction of inquiry? Ya, I mean, I guess you know good examples if you look at science in Germany in the 30s right where there were lot of biologists who built a scientific framework for the racists ideology which we find now horrifying right? So, it's an example how the context of society shapes the view in science. I mean now looking back we all consider this junk science but you know back then, this was considered, you know these were respectable scientists who measured the shape of skies and inferred all sort of weird things from that. Back then there was scientific mainstream and it I mean these are examples of how the directions of scientific inquiry is shaped by society you know and that you know this idea that we have of you know objective pursue of the truth is a bit of an idealization But I think long term and baked in the methodology is this you know emergence of sort of robust understanding but that doesn't mean that individual scientists are not subjective and that we are not shaped by the society we are part of. So, I think what makes this you know the strength of the natural science endeavor only appears on a longer time scale. So, over long-time certain explanations solidify and become independent of the fashions of the time.	**(SI: Political power structures):** if you look at science in Germany in the 30s right where there were lot of biologists who built a scientific framework for the racists ideology which we find now horrifying right? **(SI: Social values in the imapct of society):** So, it's an example how the context of society shapes the view in science **(CE-SP: Scientific activities including making measurements and inferences):** these were respectable scientists who measured the shape of skies and inferred all sort of weird things from that **(CE-AV: Objectivity and empirical adequacy):** Back then there was scientific mainstream **(CE-SP: Scientific activity):** I think long term and baked in the methodology **(CE-AV: Providing explanations that are accurate):** you know emergence of sort of robust understanding **(SI: Political power structures):** individual scientists are not subjective and that we are not shaped by the society we are part of.	**(SI: Social values in the imapct of society):** directions of scientific inquiry is shaped by society **(CE-AV: Providing expalanations that are accurate):** over long-time certain explanations solidify and become independent of the fashions of the time.

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
		FAS-P13	Social and institutional aspects of science? What do you mean by social aspects of science or you want to keep this as large as possible? Okay. What comes to my mind is how can science be used to improve the state of humanity and the state of the world	**(SI: Social values):** how can science be used to improve the state of humanity and the state of the world	
	FEA	FEA-P1	Social and institutional aspects of science. Ahhh ok so just thinking about those three terms social aspects of science I think is a no brainer it's a….we don't do scientific work in vacuum for no reason just for the way it's really cool for me to work on this thing. Its really socially driven, a lot of the scientific work, I think all of it should be driven to address a certain social need. Institutional is more how we govern in my opinion how we govern the processes and how we make sure that things are done properly in a just manner and a clean efficient effective manner. That's how I think of institutional elements or aspects of science. I don't know if that answers your question.	**(SI: Social values):** we don't do scientific work in vacuum for no reason just for the way it's really cool for me to work on this thing. Its really socially driven. **(SI: Social certification and dissemniation of scientific knowledge):** how we govern the processes **(SI: Social certification and dissemniation of scientific knowledge):** how we make sure that things are done properly in a just manner and a clean efficient effective manner	**(SI: Social values):** I think all of it should be driven to address a certain social need.

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
	FEA	FEA-P8	Yes, I guess I was not sure to think about these things even in the survey itself. One thing that comes to mind is things like social sciences like psychology, sociology where you are using data and evidence-based techniques to reach conclusions about society, about the human mind. I don't know if that's what is meant by social aspects so that's one thing that comes to mind. And another thing would be just how science can affect society and the understanding of science and the scientific methods that can influence people's thinking and behavior especially things like I said in terms of reading articles when people read articles about you know a certain type of food does this or things like that without really knowing how these conclusions are reached. I think that helping people understand how such conclusions can be reached, they can better discern if the conclusions are valid or not in a particular article or piece of research.	**(CE-SP: Making observations):** you are using data **(CE-SP:Scientific processes):** evidence-based techniques **(CE- SK: End products):** to reach conclusions about society, about the human mind. **(SI: Social values):** how science can affect society **(SI-Professional activities: informing the public about the matters of general interest):** helping people understand how such conclusions can be reached, they can better discern if the conclusions are valid or not in a particular article or piece of research.	**(SI: Social values):** the understanding of science and the scientific methods that can influence people's thinking and behavior

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
	FHS	FHS-P2	No idea. . ***Like how it operates within the institution or how science is related to society*** So, within the institution science is going to be related to what the institution has objectives to work on, to guide its researchers, to do these kinds of things. In terms of society, it's more informational let's say what we discover what we work on, we need to provide the society to provide them with clear explanations, simple explanations for them to understand and not be blown away by the kind of information that only us as academics or researchers would understand. Like for example, my own example was my parents, every time I go back home, they tell me so what did you discover? What did you work on? So, I try to give them lay words the terminology that I use, I try to explain to them what is MRI let's say because I work on MRI image processing so I try to explain to them that MRI is this big machine at the hospital where you go into a tunnel and we acquire an image. There are lots of noises coming from that machine so these are the electricity getting into the coils, they are moving to acquire the images so I try to simplify it as much as possible for them to understand.	**(SI: Social organizations and interactions):** science is going to be related to what the institution has objectives to work on, to guide its researchers, to do these kinds of things. **(CE-AV: Providing explanations):** In terms of society, it's more informational let's say what we discover what we work on, we need to provide the society to provide them with clear explanations	**(CE-AV: Providing explanations):** simple explanations for them to understand and not be blown away by the kind of information that only us as academics or researchers would understand. **(CE-AV: Providing explanations):** Like for example, my own example was my parents, every time I go back home, they tell me so what did you discover?so I try to simplify it as much as possible for them to understand.
	FM	FM-P3	Social and institutional aspects of science. When I hear this, I feel that science is not concerned with one person. Science covers a group, a society, the university, the country, the	**(SI- Social values/ Social utility):** Science covers a group, a society, the university, the country, the region and the world	

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
			region and the world so for me science and society and the world are not mutually exclusive. They are interactive.		
		FM-P4	Ah, you mean the way science moves the way science in reality now I understand the question. Science started by people working independently making observations and in their own basements, labs, Elvin (تبع) electricity(شواسمو) and others (التفاحة الي وقعت) and then moving forward with time to explain looking at stars. With time, there was much more organization, much more sharing of information (نعمل) association of societies where people would communicate to each other and mainly it was royal society for.. and the queen or the king or whoever would declare that. When Aspirin was discovered, it was somebody who was simply chewing on a piece of wood he used (كان راعي غنم) and he realized that when he is feeling sick, fever etc and when he chews on this piece of wood, he feels better بيعرق and his temperature goes down so he reported this and then of course people then started to look what is it in this wood that produces what helped him and finally they discovered acetylsalicylic acid and so on and so forth (سنة من اليوم 150/ 120 وعم نحكي شي) The beneficial effects of these early, earlier discoveries organized science more in the west	**(CE-SP: Scientific activity/ Observations and Experimentation):** Science started by people working independently making observations and in their own basements, labs, Elvin (تبع) electricity(شواسمو) and others. **(SI-Social organizations and interactions):** much more organization, much more sharing of information (نعمل) association of societies where people would communicate to each other and mainly it was royal society for.. and the queen or the king or whoever would declare that. **(CE-SP: Making predictions):** When Aspirin was discovered, it was somebody who was simply chewing on a piece of wood he used (كان راعي غنم) and he realized that when he is feeling sick, fever etc and when he chews on this piece of wood, he feels better بيعرق and his temperature goes down so he reported this and then of course people then started to look what is it in this wood that produces what helped him **(CE- SK: End products):** finally they discovered acetylsalicylic acid **(SI: Social organizations and interactions):** The beneficial effects of these early, earlier discoveries organized science more in the west than the rest of the world and now it's no more	**(SI- Financial systems):** because of this investment return you have what is now known as venture capital that is there are private people that is if you have a good idea and you have a way by which you are going to examine your idea, people are ready to give you the money, that is private people, venture capital so society moved into creating mechanisms for research to move forward

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
			than the rest of the world and now it's no more small associations, these have become big groups of peers and they transcend boundaries, peers are people working on similar subjects that you are working and therefore can evaluate whether your work is going to benefit the group or not and move science forward. And because of this existence of peers, because of the existence of peers, people I mean governments who have found the benefits of scientific discoveries OK had allocated a certain amount of funds a percentage of the tax collected to be spent on research and US was the first country to discover that this sum of money that you invest in research unlike Europe which considered it a liability يعني if you have an industry and you say I have a research lab in the industry in Europe, this was considered by labs a liability which means you should provide the needed amount of money otherwise بدها تخسرك whereas in US it was the first place where the government and banks saw this as an asset, that is if you are now putting 100 thousand $ not only you are going to recoup 100 thousand $ you are going to recoup more. This realization, the difference was that in Europe they were looking at each one. So, you may be putting the 100 thousand and losing it, I am be putting the and making 300 hundred. So, if we look at one, one, one, they look at the liabilities OK. The U.S. banks look at the overall and they found	small associations, these have become big groups of peers and they transcend boundaries **(SI: Social certification and dissemination of scientific knowledge):** peers are people working on similar subjects that you are working and therefore can evaluate whether your work is going to benefit the group or not and move science forward **(SI: Financial systems):** I mean governments who have found the benefits of scientific discoveries OK had allocated a certain amount of funds a percentage of the tax collected to be spent on research and US was the first country to discover that this sum of money that you invest in research. **(SI: Political power structures):** Europe which considered it a liability يعني if you have an industry and you say I have a research lab in the industry in Europe, this was considered by labs a liability which means you should provide the needed amount of money otherwise بدها تخسرك whereas in US it was the first place where the government and banks saw this as an asset, **(SI: Financial systems):** if you are now putting 100 thousand $ not only you are going to recoup 100 thousand $ you are going to recoup more. **(SI: Financial systems):** The U.S. banks look at the overall and they found that there was a significant, a significant return much more than any other industries so research became an asset in institutions and this really made research	

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
			that there was a significant, a significant return much more than any other industries so research became an asset in institutions and this really made research become the main stay of universities and industries not only universities but it extended to industries and now it is the combination of the two that is industries using university resources to develop their own research, there is collaboration there are joint projects and of course because of this investment return you have what is now known as venture capital that is there are private people that is if you have a good idea and you have a way by which you are going to examine your idea, people are ready to give you the money, that is private people, venture capital so society moved into creating mechanisms for research to move forward OK and this happened because as I said the product the product brought return much more than the investment that was put. This was one of the major aspects that moved it forward. There was also some political aspect and the political aspect was that faculty members which were basically researchers give governments trouble because they question, they want change so if you give them the money and send them to the lab or to the library or wherever they do their research you make them produce something good and at the same time you are keeping them a little bit away from being trouble makers.	become the main stay of universities and industries not only universities but it extended to industries **(SI: Political power structures):** There was also some political aspect and the political aspect was that faculty members which were basically researchers give governments trouble because they question, they want change **(SI: Financial systems):** if you give them the money **(CE-SP: Experimentation):** send them to the lab or to the library or wherever they do their research **(SI: Social values):** you make them produce something good	

Question Set 1	Faculty	Participant code	Answer	Analysis	Comments (Repetition / Emerging themes)
	FAFS	FAFS-P2	Application of results found on experimentations. How we take those results into applications into the society.	**(SI: Social value)**: Application of results found on experimentations into the society.	
		FAFS-P4	Institutional is like having you know laboratory facility to prove your concept you know in terms of science institutional. Community is to observe whether what you find does apply, we do see. For example, I am in the field of nutrition I know from science if you don't take this vitamin then you do have a deficiency. In the community you see the deficiency but, in the lab, you see them by a chemical reaction in a way also.	**(SI: Financial systems/facilities):** you know laboratory facility to prove your concept **(SI: Social value):** Community is to observe whether what you find does apply **(CE-SK: End products):** I am in the field of nutrition I know from science if you don't take this vitamin then you do have a deficiency **(CE-SP: Making observations):** In the community you see the deficiency **(CE-SP: Experimentation):** in the lab, you see them by a chemical reaction in a way also.	

Table D 2

Qualitative Data Coding of Question Set 2

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
FEA-P1	In one of your responses on the questionnaire items you said that you Agree with "All hypothesis is manipulative". Can you elaborate on this?	***Question repeated***. Maybe I was a bit extreme. I meant a hypothesis is your understanding of, is your understanding or your way of expressing relationship between at least two elements or two factors or two components. It's your so it's by definition the human understanding and interpretation that of of these two phenomenon and you are trying to link them so you are in the field you are right there that's what I really meant you have to; it is you who imposed this relationship so I'm thinking of an example, it's just an example, like if I do a bit more here, I am going to get a bit more there, Right! That's me I interpreted that. So that's what I meant by manipulative in the sense that it's not really manipulative, it just it requires, there's a lot a lot of it is your own perception of the relationship between these two factors and certainly we have a big say in formulating that hypothesis that could have been formulated in so many different ways.	**(CE- SM: Reasoning strategies):** your understanding or your way of expressing relationship between at least two elements or two factors or two components.	**(CE-SM: Reasoning strategies):** it's by definition the human understanding and interpretation that of of these two phenomenon **(CE-SM: Reasoning strategies):** you who imposed this relationship **(CE-SM: Reasoning strategies):** like if I do a bit more here, I am going to get a bit more there, Right! That's me I interpreted that. **(CE-SM: Reasoning strategies):** there's a lot a lot of it is your own perception of the relationship between these two factors. **(CE-SM: Reasoning strategies):** we have a big say in formulating that hypothesis that could have been formulated in so many different ways.

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
FEA-P8	In your responses on the questionnaire items, you chose Agree for "Race and ethnicity of scientists have nothing to do with science" and disagree for "Gender of scientists influences how they do science" Does this mean that you believe such aspects influence science?	So, I guess if I recall I wasn't sure what you exactly meant but in general I mean at that time the reason I chose disagree is that I don't think that gender, race, ethnicity, whatever should have an influence on what you can do with science. It should not be a barrier; it should not be something that influences what you are able to do or not able to do. Of course, if you mean that a scientist's identity influences how you analyze and collect results, I also don't think that that should be a factor, I think one should be objective and non-biased and try to keep any personal feelings or experiences out and try to be objective as much as possible. Now does it affect how you think? Well, we are all humans, you can't completely be blocked out, you have biases but otherwise I don't think it should be a barrier, it should not be an influence. Maybe it can influence your choice of the subject of study, maybe you are interested in certain topics based on certain experiences in your life but other than that I don't think. There should not be definitely any form of discrimination or bias related to science.	**(CE-AV: Objectivity in science):** I don't think that gender, race, ethnicity, whatever should have an influence on what you can do with science. **(SI: Scientific ethos of scientists/Objectivity):** It should not be a barrier; it should not be something that influences what you are able to do or not able to do. **(SI: Scientific ethos of scientists/Caution against bias):** if you mean that a scientist's identity influences how you analyze and collect results, I also don't think that that should be a factor **(SI: Social value/ Impact of culture, society and beliefs):** Maybe it can influence your choice of the subject of study, maybe you are interested in certain topics based on certain experiences in your life	**(SI: Scientific ethos of scientists/Objectivity and Caution against bias):** I think one should be objective and non-biased and try to keep any personal feelings or experiences out and try to be objective as much as possible. **(SI: Scientific ethos of scientists/Objectivity and Caution against bias):** you have biases but otherwise I don't think it should be a barrier, it should not be an influence. **(CE-AV: Objectivity in science):** There should not be definitely any form of discrimination or bias related to science.

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	In one of your responses on the questionnaire items, you chose Agree for "Laws are theories that are confirmed" Can you please elaborate?	Yes, I always get these terms confused but as far as I know you could have a theory that you propose or a hypothesis and then test, test that hypothesis and then it can become a theory and then a law. Laws are higher-up, more verifiable. Again, I don't have an exact definition but I believe that that was the hierarchy something that is more tested and there is more evidence on it. Well, you know I think everything remains a theory because there are more data that you might collect and then you might know more and then it can become a different equation or something so I don't think that we should consider anything absolutely final, we can only make inferences about the data that we have available and then there is the induction to say you know this is what it is so I don't know in terms of the actual terms used I don't know exactly how each one seems to be used.	**(CE-SP: Formulating hypothesis):** I know you could have a theory that you propose or a hypothesis **(CE-SP: Experimentation):** then test, test that hypothesis **(CE-SK: end products):** then it can become a theory and then a law **(CE-SK: end products):** Laws are higher-up, more verifiable. **(CE-AV: High confirmation):** and the hierarchy something that is more tested and there is more evidence on it. **(CE-AV: Falsification):** everything remains a theory because there are more data that you might collect and then you might know more and then it can become a different equation or something. **(CE-SM: Reasoning strategies):** we can only make inferences about the data that we have available **(CE-SP: Experimentation):** there is the induction to say you know this is what it is	
	Why did you disagree with the item which describes science as a social system?	Well, I was not sure what you meant. But I think everything that we are doing from models, experiments serves some purpose either improves quality of life, improves safety, efficiency, reduces cost in one way or another there has to be some practical application otherwise why do it so yes everything would be embedded inside society.	**(SI- Social Value):** everything that we are doing from models, experiments serves some purpose either improves quality of life, improves safety, efficiency, reduces cost in one way or another there has to be some practical application	**(SI- Social Value):** everything would be embedded inside society.

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
FAS-P5	In the questionnaire you agreed with "All scientific disciplines use the same scientific method" Did you mean the process that you just explained, the model?	Yes, it is this scientific model that is being used. Others can deviate a little bit when we talk about theoretical sciences; there we don't have a possibility to gather data so I have to rely on an axiom or a theorem or my knowledge of something that has been developed based on data. There is a problem when we use equations if we are talking theoretically there would be domains in which they do not apply, here you need to prove them using other techniques so not everything is based on data but the applied sciences yes.	**(CE- SP: Scientific process):** it is this scientific model that is being used. **(CE- SP: Data collection):** there we don't have a possibility to gather data **(CE- SK: End products):** I have to rely on an axiom or a theorem or my knowledge of something that has been developed based on data. **(CE- SP: Scientific processes):** if we are talking theoretically here you need to prove them using other techniques	
	Just as a follow-up to what you just discussed, in one of the items of the questionnaire which is "Science takes place in institutions such as universities and research centers". You disagreed with this item. Can you explain why?	Definitely, institutional science I am patent and want to get a grant and all of these things they have to take place in institutions also because the outcome of science is regulated. For instance, if I come up with a bomb my outcome would be definitely regulated but you do science everyday the collection of the data doesn't have to be at the institution. Of course, you can do science in your free time. I don't think that science is limited to an institution but its output and the ease of doing it has to happen within an institution.	**(SI- Financial systems):** I am patent and want to get a grant and all of these things **(SI-Social organizations and interactions):** they have to take place in institutions **(SI- Scientific ethos/ Social and ethical norms):** the outcome of science is regulated.	**(SI- Scientific ethos/ Social and ethical norms):** if I come up with a bomb my outcome would be definitely regulated **(SI-Social organizations and interactions):** its output and the ease of doing it has to happen within an institution.

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	You totally agree with "Politics or policies of governments doesn't influence science" how is that?	In order to do the science, you need to frame it if I want a grant for example to be very frank. If we need a grant to research a certain question, it has to be relevant to the society, and relevant to the development. It has to has a developmental impact or it has to go in a certain business perspective as drugs and anything that goes there. Otherwise, I see science is not well supported when you deal with this. However, there are sciences that do not require grants and all of this and there are many scientists who work on developing science as an absolute or scientific methods like they were developed before especially on the theoretical approach where you don't really need policy to guide this. So, both are there. I think it depends on the type of science that you will do whether it should have an impact on society or whether it is science in absolute when you inquire about something as a to increase knowledge. So, there are the two sciences of it.	**(SI-Financial systems):** In order to do the science, you need a grant to research a certain question **(SI- Social values):** it has to be relevant to the society, and relevant to the development **(SI- Social values):** it has to go in a certain business perspective as drugs and anything that goes there. **(CE-SK: Accumulation of knowledge):** scientists who work on developing science as an absolute or scientific methods like they were developed before especially on the theoretical approach	**(SI- Social values):** It has to has a developmental impact **(SI- Social values):**whether it should have an impact on society **(CE-SK: Accumulation of knowledge):** science in absolute when you inquire about something as a to increase knowledge
	Now I understand why you disagreed with "All branches of science use observations"	Oh yes because we have the theoretical science. There are observations sometimes that you cannot use. You use observations but you infer things that have happened in the past based on observations that are happening now. This is not direct observation this is indirect but I am using the model that applies now.	**(CE-SP: Making observations):** You use observations **(CE-SM: Reasoning strategies):** you infer things that have happened in the past based on observations that are happening now **(CE-SK: Models):** I am using the model that applies now	

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	In what sense do you agree with "The gender of scientists influences how they do science"?	Positively actually. I see it positive since I talk about myself so I have to come to realize that I am a forward, I am a backward thinker so if I have an equation, I don't see it as an equation but I can reproduce this equation based on a case study that I need for my science. So, this is how I am a backward thinker. I don't see the equation in absolute but I see it applicable in my field. And this is actually very positive in a way because it allows you to concretize science. This is good for theoretical math and for using the tool of math to apply it; but sometimes people cannot go this way and people cannot go this way either. So, it is important to. Maybe, it doesn't have to do with gender, but also the fact that this interdisciplinarity that women have allows them to also focus on different aspects in science rather than in one line. But again, I am speaking about myself, I don't know other women scientists in our field, but I can compare to colleagues, male colleagues that I have worked with in the same field and actually we have discussed this once. When I was solving the equation backward, specific equation, he was solving it forward but we couldn't meet halfway. So, I think that, also the intuition have a say, for instance how to set a hypothesis, it's your feeling of your surrounding that makes you set a hypothesis, while maybe other people	**(CE-SM: Reasoning strategies):** I am a backward thinker so if I have an equation, I don't see it as an equation but I can reproduce this equation based on a case study that I need for my science. **(SI- Political power structures/ Gender influence):** the fact that this interdisciplinarity that women have allows them to also focus on different aspects in science rather than in one line. **(SI- Political power structures/ Gender influence):** I am speaking about myself, I don't know other women scientists in our field, but I can compare to colleagues, male colleagues that I have worked with in the same field and actually we have discussed this once. When I was solving the equation backward, specific equation, he was solving it forward but we couldn't meet halfway. **(CE-SP: Data collection):** I could have a hypothesis and go fetch the data. **(CE-AV: Evidence based nature/ Empirical adequacy):** at the end everyone has to get to the point of data and to proving. **(CE-SM: Reasoning strategies):** all about how you get to this hypothesis, how you get to working in different paths at the same time, how you get to use specific solutions	**(Emerging theme: Intuition):** I think that, also the intuition have a say, for instance how to set a hypothesis **(Emerging theme: Feeling):** it's your feeling of your surrounding that makes you set a hypothesis **(Emerging theme: Feeling):** I am in connection with my environment a lot, I feel it

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
		need the data to set a hypothesis. I could have a hypothesis and go fetch the data because I am in connection with my environment a lot, I feel it, and because I collect a lot of data so at the end, I am in connection with the spring that I am monitoring or the well so this is where I but at the end everyone has to get to the point of data and to proving. But it's all about how you get to this hypothesis, how you get to working in different paths at the same time, how you get to use specific solutions. These are maybe affected by gender; I don't know or simply by a state of mind that is independent of gender. I am not really sure.		
	You disagree with "Theories and laws are forms of scientific knowledge but models are not" and you think of models as being used to understand phenomena. Can you elaborate on this?	Yes, I will talk about this in discipline specific and as a modeler as well because I do models, not models of, there are models in education no. Here I am talking about models for example I have a certain phenomenon, there are governing equations that go into it. I develop a model based on these governing equations and this model can be in different ways. It can be a process-based model where there are physics involved or math. It can be simple model as in and out and I am knowing what is happening inside so I am not able to understand the phenomenon itself but I understand how an out reacts to an in. And there is a third part which is a completely statistical model where I don't even try to	**(CE-SP: Constructing models):** I am talking about models for example I have a certain phenomenon, there are governing equations that go into it. **(CE-SP: Model as a scientific practice):** It can be a process-based model where there are physics involved or math **(CE-SP: Model as a scientific practice):** It can be simple model as in and out and I am knowing what is happening inside so I am not able to understand the phenomenon itself but I understand how an out reacts to an in. **(CE-SP: Model as a scientific practice):** a completely statistical model where I don't even try to reproduce what is happening inside. I am just looking at a certain	**(CE-SP: Model as a scientific practice):** These three are different models that allow us to understand the phenomenon as in what type of in would give me what type of result; but it is not set in stone, there are limitations, uncertainties, your perceptions, over-simplification or over-complexity

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
		reproduce what is happening inside. I am just looking at a certain inference of an output form an input based on pure statistics. These three are different models that allow us to understand the phenomenon as in what type of in would give me what type of result; but it is not set in stone, there are limitations, uncertainties, your perceptions, over-simplification or over-complexity, so it gets you closer to reality but it's not, not; it might be case specific as well. Whereas when I talk about theory in general, it has been proven in absolute and not disproven; so, we are closer to reality in that sense and because we have control over the variables in a certain theory. If I talk about the theory of evolution processes are involved in it as well, but most of the time these have taken a lot of time to be proven. It has some history which allows that with time it has proven itself and it has less chance to be disproven. Model is different, it is very case specific I believe.	inference of an output form an input based on pure statistics. **(CE-SK: Knowledge):** theory in general, it has been proven in absolute and not disproven. **(CE-SM: Manipulation of variables):** we have control over the variables in a certain theory. **(CE-AV: Accuracy and High confirmation):** theory of evolution processes are involved in it as well, but most of the time these have taken a lot of time to be proven	

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	Why you disagree with: "Classification helps scientists explain and predict phenomena"? Let's say the periodic table, classification helped them predict certain elements.	Classification we are talking ontological classification? The only way where I use classification is to classify general approach to a phenomenon but not classification in terms of words. Let's say if I take something that is mathematical let's say decay that can be put in a very easy equation. If I look at different phenomena in geology, you can see the decay in chemistry, you can see the decay in quantities, you can see the decay in so many aspects. If I look at it in physics, the decay is also found when I look, not decay, we were talking exponential functions, you can find them everywhere. This is where I am able to classify those phenomena are not so random and they obey certain physical approaches which are mathematical at the end but I think that classification in terms of ontological would prevent people from actually looking beyond the term itself. Maybe there is something that I am overlooking, just because that I have said this in this cluster and second, I am not looking at overlapping processes if I classified it. But maybe if you give me an example. ***I: Let's say the periodic table, classification helped them predict certain elements.*** P8: They can be helpful but I feel you are putting science too much into a box. In some, we have to. Science is varying with time. If I	**(CE- SP: Classification as a practice):** The only way where I use classification is to classify general approach to a phenomenon but not classification in terms of words. **(CE- AV: Openess):** They can be helpful but I feel you are putting science too much into a box. **(CE-AV: Novelty, falsifiability):** Science is varying with time. **(CE-SM: Reasoning strategies):** I will never teach someone by having him memorize the periodic table or time scale of geology but I teach how we did the classification. **(CE-SK: Scientific knowledge):** I call this transfer of knowledge than the transfer of the know-how.	**(CE-SP: Classification as a practice):** Let's say if I take something that is mathematical let's say decay that can be put in a very easy equation. If I look at different phenomena in geology, you can see the decay in chemistry, you can see the decay in quantities, you can see the decay in so many aspects. If I look at it in physics, the decay is also found when I look, not decay, we were talking exponential functions, you can find them everywhere. This is where I am able to classify those phenomena are not so random and they obey certain physical approaches which are mathematical **(CE-SM: Reasoning strategies):** Maybe you might find someone who is specialist in Helium and doesn't know anything about the other elements but if he understands how noble gases function then it's not important to know its mass, yet the process is more important than a number which defines something.

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
		want to put let's say a periodic table of half lives of radioactive isotopes with time it is becoming more analytical residues so I don't think maybe we can advise that such things exist but not to rely exclusively on them. I will never teach someone by having him memorize the periodic table or time scale of geology but I teach how we did the classification; maybe other things might come up. I don't like to put science in a box even though I know its systematic but not bounded. Maybe you might find someone who is specialist in Helium and doesn't know anything about the other elements but if he understands how noble gases function then it's not important to know its mass, yet the process is more important than a number which defines something. I call this transfer of knowledge than the transfer of the know-how.		
FAS-P7	On one of the items on the questionnaire you disagreed that all scientific disciplines use the same scientific method. Can you elaborate?	Yes, the scientific method for me is about experimentation. For me a scientific method is based on so you have to do the experiment, and then you have results, you assess these results and you try to improve and to optimize your experiment to improve more and more the result. So, this was my. So being physics, biology or chemistry so you have to do an experiment and to assess the results.	**(CE-SP: Experimentation):** the scientific method for me is about experimentation **(CE-SK: Scientific Knowledge):** you have results, **(CE-AV: High confirmation):** you assess these results	**(CE-SP: Experimentation):**you have to do the experiment **(CE-AV: High confirmation):** you try to improve and to optimize your experiment to improve more and more the result. **(CE-SP: Experimentation):** you have to do an experiment and to assess the results

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	How do you think of scientific models? In one of the items, you agreed that "Theories and laws are forms of scientific knowledge but models are not" and on another item you agreed that "Scientists use models to understand phenomena" or "They are being tools to represent the world". Can you elaborate more?	Ya, in fact when I answered this question, I went directly to a course that I teach about chemical kinetics. So chemical kinetics if you want to predict for example the rate of a chemical reaction, you go and you check if there are some models already. So the model for example says that OK this rate, this chemical compound is being degraded through a first order rate or second order rate but you cannot predict another compound how its degradation will be. To use the model of compound Y or compound X, you cannot do it, you have to do the experiment OK on compound Y to make sure if the behavior of compound Y is the same as compound X. But finally, once you have similar, a family of compounds, you might in this case predict a model and use just one model for a variety and this is very helpful because it will let you gaining a lot of time, we will not really spend months and years to search and do research while there is a model that you can apply, a model based of course on experimentation and from this experimentation we define a model and this model is based on a theoretical approach as well. So always you start with a theoretical approach, then we go to the experiment, we get a model and then we compare this model to the theoretical approach, they match or they don't match and most of the cases they	**(CE-SP: Making predictions):** chemical kinetics if you want to predict for example the rate of a chemical reaction **(CE-SK: Scientific Knowledge):** you check if there are some models already **(CE-SP: Experimentation):** you have to do the experiment OK on compound Y to make sure if the behavior of compound Y is the same as compound X	**(CE-SK: Scientific Knowledge):** the model for example says that OK this rate, this chemical compound is being degraded through a first order rate or second order rate **(CE-SP: Making Predictions):** once you have similar, a family of compounds, you might in this case predict a model **(CE-SP: Experimentation):** a model based of course on experimentation and from this experimentation we define a model and this model is based on a theoretical approach as well. **(CE- SP: Experimentation):** you start with a theoretical approach, then we go to the experiment, we get a model and then we compare this model to the theoretical approach, they match or they don't match **(CE-SP: Experimentation):** we have to investigate more and more to understand why it works with this and it does not work with that.

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
		match. If they don't match, then something is weird here and we have to investigate more and more to understand why it works with this and it does not work with that.		
	Why do you think that all branches of science use observations?	Coming back to the same idea that for me science is experimentation. You do an experiment; you observe what is happening, you observe through visual observation first, second you do analysis, you collect the data and then you work on this data so this means that yes you have to observe, you have to do the experiment, very important, observation is crucial.	**(CE-SP: Experimentation):** for me science is experimentation. **(CE-SM: Reasoning strategies):** second you do analysis **(CE- SP: Data Collection):** you collect the data	**(CE-SP: Experimentation):** You do an experiment; you observe what is happening, you observe through visual observation first **(CE-SP: Making observations):** you have to observe **(CE-SP: Experimentation):** you have to do the experiment **(CE-SP: Experimentation):** observation is crucial.
	You agree with the item that "Laws are theories that are confirmed" Does this mean that you think of laws as being more verifiable than theories?	Yes, because a law is based on some experiments. Let's say the gas laws are based on experiments so we know that if you heat a balloon containing air, if you heat it a little bit, the balloon will expand so it's based on experiment so from here we get the law about, the gas laws. The other one, the theory is announced first and then people and researchers try to check if this theory is valid, they prove it by experimentation.	**(CE-SP: Experimentation):** a law is based on some experiments **(CE- SP: Experimentation):** the theory is announced first and then people and researchers try to check if this theory is valid, they prove it by experimentation.	**(CE- SP: Experimentation):** the gas laws are based on experiments so we know that if you heat a balloon containing air, if you heat it a little bit, the balloon will expand so it's based on experiment

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
FAS_P12	In one of the items of the questionnaire that is "All scientific disciplines whether biology, physics, and chemistry use the same scientific method" Can you elaborate on your response?	I mean the same underlying philosophy. I meant maybe the details of the method differ but the same underlying philosophy.	**(CE-SP: Experimentation):** the details of the method differ but the same underlying philosophy.	
	In one of the items of the questionnaire, you weren't sure about "Theories and laws are forms of scientific knowledge but models are not." Yet, on another item you agree with "Scientists build and use	Yes, I guess we can consider them as, as. Models are important tools and so, I mean I mean I guess it a sort of continuum on some level everything is a model but usually a model when you think what's the difference between a model and a law and a theory usually models are more specific than a theory. Models are essential tools. Everything and you have to have a model I mean in a sense scientific the sense of doing science is the sense of model building and you have to have a model to be able to make predictions and then when the model becomes successful and broadly applicable it turns into a theory or into a law and this then	**(CE-SP: Model as tools):** Models are important tools **(CE-SP: Model as a scientific practice/experimentation):** the sense of doing science is the sense of model building **(CE-SP: Making predictions):** to make predictions **(CE-AV: Accuracy and High confirmation):** when the model becomes successful and broadly applicable it turns into a theory or into a law and this then gets accepted into the cannon of science **(CE-SP: Experimentation):** the model is the working hypothesis that is not yet part of the cannon, part of the knowledge	**(CE-SP: Model as tools):** Models are essential tools. **(CE-SP: Model as a scientific practice/experimentation):** It's always model-building. **(CE-SP: Making predictions):** A simplification of reality that allows you to make predictions **(CE-SP: Model as a scientific practice from making predictions to reaching a verified scientific knowledge):** you need that piece to have falsifiable predictions and once you know once you have the

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	models to understand scientific phenomena". Does this mean that you think of models as scientific practices or you consider them as forms of knowledge?	gets accepted into the cannon of science so that's, so then I said then you have different terminology, where you distinguish between a theory and a model you know maybe the model is the working hypothesis that is not yet part of the cannon, part of the knowledge but it's an essential piece of the endeavor. It's always model-building. A simplification of reality that allows you to make predictions and you need that piece to have falsifiable predictions and once you know once you have the model, suddenly you open, once you have a verified model then you open to highly new spaces and I guess sort of the central, in Biology I would say the prime example of model building is Mendel, Mendel's genetics way where he had this idea of a model that generated his data.	**(CE-SP: Data collection):** Mendel's genetics way where he had this idea of a model that generated his data.	model, suddenly you open, once you have a verified model
	You agree with one of the items of the questionnaire which is "Laws are theories that are confirmed" so does this mean that you think of laws as more verifiable knowledge than theories?	So. Laws are theories that are confirmed but it doesn't necessarily mean, not all confirmed theories are laws let me put it this way. I would say the prime example is maybe evolution, Darwin's theory of evolution that is, that its main tenets are broadly confirmed repeatedly in all sorts of different disciplines you know the entire theory of genetics that emerged after Darwin the sequences, bla bla bla, everything confirmed Darwin's theory but the theory itself is too idiosyncratic to be easily phrased as a law. Right? So that's my, yes, I think one can consider laws as	**(CE-SK: Laws and theories):** Laws are theories that are confirmed but it doesn't necessarily mean, not all confirmed theories are laws let me put it this way. **(CE-AV: High confirmation):** Darwin's theory of evolution that is, that its main tenets are broadly confirmed repeatedly in all sorts of different disciplines you know the entire theory of genetics that emerged after Darwin the sequences, bla bla bla, everything confirmed Darwin's theory	(CE- SK: Laws and theories): I think one can consider laws as confirmed theories but not all confirmed theories become a law or can be formulated as a law.

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
		confirmed theories but not all confirmed theories become a law or can be formulated as a law.		
	Since you talked about science as an objective collective endeavor that shouldn't be affected by subjective bias or cultural aspects, then can you explain why you weren't sure about one of the items of the questionnaire which is "The gender of scientists influences how they do science"?	Alright so. I think you know like everything, everything that is part of the person of the scientist influences how they do science including the gender I mean not necessarily, I am not sure whether in a predictable way but you know everything that makes a particular person influence, I mean we do science with our brain that is part of ourselves. Sure, gender influences and all that is fine you know like I was not quite sure whether you know whether in a necessarily in a very predictable coherent way to say: Oh, this is typical for a female was this male, way of doing things. So, alright I think the best is to think of this is in terms of a process: you generate ideas, you have hypotheses and then you test them and the idea-generating part is strongly influenced by everything that makes a person and shapes the experience of a person and that is race, gender and everything else and that's good but the goal and the scientific method is set-up in such a way that then the hypothesis-testing part is should be independent of the person right. I mean this ideal is not always realized but this is how science should work and for the first part you know the more diversity experiences of people who come up with ideas, the better	**(SI- Political power structures/gender):** I think you know like everything, everything that is part of the person of the scientist influences how they do science including the gender. **(CE-SP: Posing questions/Making inferences):** I think the best is to think of this is in terms of a process: you generate ideas **(CE-SP: Formulating hypothesis):** you have hypotheses **(CE-SP: Experimentation):** you test them **(CE-AV: Objectivity):** the hypothesis-testing part is should be independent of the person right **(SI- Social certification and dissemination of scientific knowledge/ Collaboration):** this is how science should work and for the first part you know the more diversity experiences of people who come up with ideas, the better right **(SI- Social certification and dissemination of scientific knowledge/ Evaluation and validation):** the filtering part where it gets tested and compared against the data **(CE-AV: Objectivity):** nature should be the ultimate judge that should be the independent of the person who does it	**(SI- Political power structures/gender):** everything that makes a particular person influence, I mean we do science with our brain that is part of ourselves **(SI- Political power structures/gender, race etc)**: the idea-generating part is strongly influenced by everything that makes a person and shapes the experience of a person and that is race, gender and everything else and that's good. **(CE-AV: Objectivity):** I think on the long term it bends towards that it bends towards objectivity

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		right but then the filtering part where it gets tested and compared against the data and nature should be the ultimate judge that should be the independent of the person who does it. That's the idea, whether it always works like that is another question but that's the idea and the endeavor towards this and I think on the long term it bends towards that it bends towards objectivity		
FAS-P13	In what sense you believe that all scientific disciplines use the same scientific method?	Because. Again, the essence of science as per an example, I am an experimental scientist, the essence of science is observation and measurements and interpretation and in all four the basic sciences geology, physics, chemistry and biology observation, measurements, and analysis is common core to all of them and it is based on these three pillars that we can build scientific theories.	**(CE- SP: Experimentation):** the essence of science is observation and measurements and interpretation	**(CE- SP: Experimentation):** observation, measurements, and analysis is common core to all of them
	You disagree with the item which is "Theories and laws are forms of scientific knowledge but models are not." Can you explain your answer?	What I am trying to say is that models help us understand the science but they are not knowledge per say. This is what I meant if that clarifies.	**(CE-SP: Tools for experimentation):** models help us understand the science but they are not knowledge per say	

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	So, you agree that the science curriculum should cover these aspects not only the bulk knowledge?	Oh YES, YES, 100 percent. Actually, I think there is a major shortcoming in the sciences these days. Sometimes we do produce excellent scientists who are not as commonly referred to as socially aware. And I think the social awareness and the humane aspect of a person should be intimately coupled to the science.	**(SI- Scientific ethos / social and ethical norms):** we do produce excellent scientists who are not as commonly referred to as socially aware.	**(SI- Scientific ethos: Social and ethical norms):** social awareness and the humane aspect of a person should be intimately coupled to the science.
	In one of your responses on the questionnaire items you agree with "The gender of scientists influences how they do science" Can you elaborate on this?	You see because we are all human beings and science is always seen as something that is not related to emotions and to background and we see science as hard core basic science as molecules interacting or something like that but in our interpretation you can always sense the baggage that a person has carried over his/her lifetime and obviously gender makes a big difference because the experience of a man as a physicist over the years will be significantly different from the experience of a woman as a physicist over the years.	**(CE-AV: Objectivity):** science is always seen as something that is not related to emotions and to background **(CE-SK: Scientific Knowledge/ hard core):** we see science as hard core basic science as molecules interacting or something like that **(SI-Political power structures: Life experiences and gender):** in our interpretation you can always sense the baggage that a person has carried over his/her lifetime and obviously gender makes a big difference	**(SI-Political power structures: Life experiences and gender):** experience of a man as a physicist over the years will be significantly different from the experience of a woman as a physicist over the years.
	In what sense do you agree with "Laws are more verifiable scientific knowledge than theories"?	The way I see laws is that they are actually theories that have been confirmed experimentally. This is the way I understand laws of physics that is theory and once you verify it in a lab or through your observation or through your measurement then it becomes a law so it's automatic.	**(CE-AV: Empirical adequacy and High confirmation):** laws is that they are actually theories that have been confirmed experimentally **(CE-SP: scientific inquiry processess):** laws of physics that is theory and once you verify it in a lab or through your observation or through your measurement then it becomes a law	

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
FAFS-P2	Do you think that all branches of science have this same step-to-step order of doing science?	More or less. Yes.	**(CE-SP:** step to step method to doing science)	
	In one of your responses on the questionnaire items you agreed with “Theories and laws are forms of scientific knowledge but models are not” and you also agreed with “Scientists use models to understand phenomena or they are tools to represent the world” Does this mean that you think of scientific models as tools.	Well, the practice is very important but you can always explain while people are doing something in a scientific way. People have been growing their land I am giving you an agricultural example since الله أعلم and now we know why they are growing, or why they shouldn’t be growing.	**(CE-AV: Providing explanations):** you can always explain while people are doing something in a scientific way	**(CE-AV: Providing explanations):** now we know why they are growing, or why they shouldn’t be growing.

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	Do you think that "All branches of science use observations"?	Oh definitely. Observation is one step of a very, actually a good scientist has to be a very good observer. If you are not a good observer then. Because you start with something and you get a result. You have to know what happened here in between and that's the observation and especially in applied science. You know there are basic science and applied science, like you go in basic science and now even, they are creating very complicated instruments to be able to observe the basic science. In chemistry, for instance, we will take a compound A and B to get C and D. We know what we put in and we know what we get out; what we don't know is the process. Now NOBEL PRIZES were given lately to scientists who are figuring out what's going on between A and B. I can give you another example that is very you can relate to when you go from dark to light, you close your eyes a little bit and then you can open your eyes. I think Dr. Pauling in UC Berkely got NOBEL PRIZE, he discovered 12 compounds in the eye develops between the eye being in the darkness or the light and he identified these 12 compounds and now they are even taking pictures of these compounds so the observation is the most important thing, it's very important.	**(CE-SP: Making observations):** Observation is one step of a very, actually a good scientist has to be a very good observer **(CE-SK: Scientific Knowledge/ result):** Because you start with something and you get a result. **(CE-SM: Reasoning strategies):** You have to know what happened here in between and that's the observation and especially in applied science. they are creating very complicated instruments to be able to observe the basic science. **(SI- Social organizations and interactions):** Now NOBEL PRIZES were given lately to scientists who are figuring out what's going on between A and B.	**(SI- Social intercations and organizations):** I can give you another example that is very you can relate to when you go from dark to light, you close your eyes a little bit and then you can open your eyes. I think Dr. Pauling in UC Berkely got NOBEL PRIZE, he discovered 12 compounds in the eye develops between the eye being in the darkness or the light and he identified these 12 compounds. **(CE-SP: Making observations):** the observation is the most important thing

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	Why do you think that "Laws are more verifiable forms of scientific knowledge than theories"?	Well in basic in in you see like if you go to Math, and physics and Chemistry and I don't know, this is there are no theories here much. It is mainly one and one equal two. In theories you start philosophizing; when you go to applied, in humanity, relationships and things like that you philosophize, you interpret, different people interpret those results differently and here comes many people don't accept that because it doesn't depend on a scientific fact or a scientific data number. But once you have a number to me خلص no discussion.	**(CE-AV: High confirmation):** It is mainly one and one equal two. **(CE-SM: Various reasoning strategies):** In theories you start philosophizing you philosophize, you interpret, different people interpret those results differently **(CE-AV: Empirical adequacy and High confirmation):** many people don't accept that because it doesn't depend on a scientific fact or a scientific data number.	**(CE-AV: Empirical adequacyand High confirmation):** But once you have a number to me خلص no discussion.
FAFS-P4	How do you think of scientific models? Are they forms of knowledge or are they tools to represent the world or are they practices/ scientific practices?	I think you know models in science change with time. There is no fixed model because the more we get knowledge, the more we will be willing to change the models in a way so I don't think we should really be sticking to one type of scientific model. We should really be open-minded to different things.	**(CE-AV: Falsifiability):** models in science change with time. **(SI- Scientific ethos/ Openess):** We should really be open-minded to different things.	**(CE-AV: Falsifiability):** There is no fixed model because the more we get knowledge, the more we will be willing to change the models in a way

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	In one of the questionnaire items, you said that you agree with "All branches of science use observation". Can you elaborate on this?	Yes, what I mean, observation what I mean you see sometimes you see a trend of a disease or a behavior of something and so you need to really explain how it is really you know why did this come and so to do this I think you have to dig down to see you know the basic causes I think not to look at superficial changes in a way. I don't know if I answered your question. In my field for example, if there is a sign of lets say night blindness I need to dig down to see what is the causes of night blindness and you know I will find the vitamin A and so on then to explain it to people that this came from you know your behavior, your eating behavior, you are not consuming this and this in order to explain what happened to them because a lot of time certain disease and certain things happen and people you know they say willingness of God or I didn't do something well. Last time I had a guy who was really, really ill and he said I told him go to a doctor; he told me it's my fault I went to Bekaa, certain prophet I promised him I will pay for people if I do something but I didn't pay money and I think this made me ill I told him I don't think that prophet is objective to punish people I think doctors would really make life better so I think he was convinced that it is his fault and that he should suffer.	**(CE-AV: Making observations):** observation what I mean you see sometimes you see a trend of a disease or a behavior of something and so you need to really explain how it is really you know why did this come and so to do this I think you have to dig down to see you know the basic causes I think not to look at superficial changes in a way. **(CE-SM: Reasoning strategies):** In my field for example, if there is a sign of lets say night blindness I need to dig down to see what is the causes of night blindness **(CE-SK: Resultant knowledge):** you know I will find the vitamin A **(CE-AV: Providing explanations):** then to explain it to people that this came from you know your behavior, your eating behavior, you are not consuming this and this in order to explain what happened to them because a lot of time certain disease and certain things happen	

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	Do you think that "Laws are more verifiable knowledge than theories"?	Yes, they are supposed to be based on almost concrete facts. Theory is you still in the testing period to and then if you really manage to confirm your theory then maybe you can move it into law.	**(CE-AV: Empirical adequacy and High confirmation):** they are supposed to be based on almost concrete facts **(CE- SP: Experimentation/testing):** Theory is you still in the testing period	**(CE-AV: Empirical adequacy and High confirmation):** if you really manage to confirm your theory then maybe you can move it into law
	In one of the items that is "All hypothesis testing is manipulative" you weren't sure about this item. How do you think about it?	Because you can test hypothesis by different methods and lets see what I do have in mind like for example at one stage we had the example of anti-oxidant that is good to prevent the disease and so on in the laboratory and there was some study that if we consume fruits and vegetables disease goes down so everybody goes Oh because fruits and vegetables have anti-oxidants so they always jump into this but when you consume fruits and vegetables, you change a lot of parameters, not only this in fact if you give supplement of anti-oxidant does not do anything that's why if there is something trendy you try to link your hypothesis to this trendy thing which doesn't really always gives explanations especially in terms of diet, you know if you modify if you are eating more fruits and vegetables this means you are eating less meat so does it the less meat or the more fruit you know so people try to look at one side of the equation I think this is wrong especially in nutrition that's why we always have confusing data. Every time someone says this is healthy, this is not healthy.	**(CE-SM: Various reasoning strategies):** you can test hypothesis by different methods **(CE-SM: Manipulation of variables):** at one stage we had the example of anti-oxidant that is good to prevent the disease and so on in the laboratory and there was some study that if we consume fruits and vegetables disease goes down so everybody goes Oh because fruits and vegetables have anti-oxidants so they always jump into this but when you consume fruits and vegetables, you change a lot of parameters, not only this in fact if you give supplement of anti-oxidant does not do anything **(CE-AV: Providing explanations):** if there is something trendy you try to link your hypothesis to this trendy thing which doesn't really always gives explanations especially in terms of diet	**(CE- SM: Manipulation of variables):** you know if you modify if you are eating more fruits and vegetables this means you are eating less meat so does it the less meat or the more fruit you know so people try to look at one side of the equation I think this is wrong especially in nutrition that's why we always have confusing data

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
FM-P3	Can you explain why you disagreed with one of the items of the questionnaire which is “Race and ethnicity of scientists have nothing to do with science”?	NO. Not at all. Absolutely not at all. In the previous question I meant genetic diseases, cancer incidents, but not about scientists. Not at all. Definitely not at all. A scientist can be from any place in the world, any race that shouldn’t affect the outcome.	**(CE-SK: Scientific knowledge):** In the previous question I meant genetic diseases, cancer incidents **(CE-AV: Objectivity):** A scientist can be from any place in the world, any race that shouldn’t affect the outcome.	
	Can you explain why you agreed with “All scientific disciplines use the same scientific method”?	Ah. We cannot say all there is nothing all. Maybe I’ve communicated it by mistake. Scientific, the way scientists should work in general in my disciplines, biomedical sciences, you should have a hypothesis then you should do testing and at the end statistically either accept or refute or reject the hypothesis. Now depending on the scientific discipline, the approach, the scientific approach may differ but we always have to have a question, What’s the question? What are we asking? There should be a scientific way to conduct this, to analyze it objectively and then to come with the output. Ok, so the way we go through may differ from one discipline to the other but in general scientific knowledge, scientific inquiry should be similar in a way, in the essence of it, but the different ways to do it may differ.	**(CE-SP: Formulating hypothesis):** you should have a hypothesis **(CE-SP: Experimentation):** you should do testing **(CE-AV: Empirical adequacy and high confirmation):** at the end statistically either accept or refute or reject the hypothesis. **(CE-SM: Various reasoning strategies):** depending on the scientific discipline, the approach, the scientific approach may differ **(CE-AV: Objectivity):** There should be a scientific way to conduct this, to analyze it objectively **(CE-SK: Scientific knowledge):** to come with the output	**(CE-SM: Various reasoning strategies):** in general scientific knowledge, scientific inquiry should be similar in a way, in the essence of it, but the different ways to do it may differ.

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	Do you think that individual subjective prejudices of scientists affect this process that you were just explaining?	It shouldn't. When I say it should be objective like in our disciplines, we have something, we always have controlled treatments. In clinical trials, we have sometimes, the scientists that test don't know which clinical groups are the control and which are the treatment, or the research assistants sometimes when they look under the microscope sometimes my students ask me: Look at these cells. Ok. I tell them don't tell me if they are treated or not. So, I look, like just to be as objective as possible and I look and I tell them Ahaa, I think these cancer cells are treated. Correct? So, definitely the scientific experiments should be set in a way to minimize bias, to minimize subjectivity because as human beings, we are always, we may be, even if scientist unwillingly subjective just because I want my treatment to work, I would look for anything to show that the treatment is working whether on the cells, or the animals or the patients. So, the scientific inquiry, the methods should lessen this as much as possible.	**(CE- AV: Objectivity):** When I say it should be objective like in our disciplines, we have something, we always have controlled treatments. **(SI- Scientific ethos/ Scientists' caution against bias)** as human beings, we are always, we may be, even if scientist unwillingly subjective just because I want my treatment to work, I would look for anything to show that the treatment is working whether on the cells, or the animals or the patients.	**(CE-AV: Objectivity):** In clinical trials, we have sometimes, the scientists that test don't know which clinical groups are the control and which are the treatment, or the research assistants sometimes when they look under the microscope sometimes my students ask me: Look at these cells. Ok. I tell them don't tell me if they are treated or not. So, I look, like just to be as objective as possible and I look and I tell them Ahaa, I think these cancer cells are treated. Correct? **(CE-AV: Objectivity):** the scientific experiments should be set in a way to minimize bias, to minimize subjectivity **(CE-AV: Objectivity):** the scientific inquiry, the methods should lessen this as much as possible.
	On one of the items of the questionnaire you disagreed with "Theories and laws are	Yes, models can help us to understand what we see, models can help us to get conclusions so definitely models are important too. Because sometimes we cannot come with a theory, but we can come up with	**(CE-SP: Model as a scientific practice):** models can help us to understand what we see, models can help us to get conclusions	**(CE-SP: Model as a scientific practice):** we can come up with a model to explain what we observe

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	forms of scientific knowledge but models are not" Does this mean that you see models as knowledge themselves?	a model to explain what we observe and with time that might translate into theories.		
	Can you explain why you agreed with "Laws are more verifiable scientific knowledge than theories"?	I would put laws on top of theories. Laws is when we have so many theories, it's well established you come with a law. Theories, you test a theory Ok. One thing you learn in science, in biomedical sciences in our discipline nothing is absolute. I mean even we used to have the dogma of science we used to say the genetic material, DNA gives RNA and RNA would give proteins that was sacred DNA to RNA to protein OK. And then after that with the discovery of RNA viruses, of retroviruses we discovered that actually this DNA to RNA to protein can be reversed, where the RNA virus gives DNA, RNA can give DNA so that's the central dogma was broken, the central law was broken so really laws there are no absolute laws. In science you have to be open-minded because you may be surprised how exceptions may were central laws, dogmas, theories may be broken and you should be open-minded to this. The biggest discoveries	**(CE-AV: Falsifiability):** in biomedical sciences in our discipline nothing is absolute. **(SI-Scientific ethos/ Openess):** In science you have to be open-minded **(CE-AV:Empirical adequacy and objectivity):** make sure to have enough evidence to support it be objective as much as possible.	**(CE-AV: Falsifiability):** I mean even we used to have the dogma of science we used to say the genetic material, DNA gives RNA and RNA would give proteins that was sacred DNA to RNA to protein OK. And then after that with the discovery of RNA viruses, of retroviruses we discovered that actually this DNA to RNA to protein can be reversed, where the RNA virus gives DNA, RNA can give DNA so that's the central dogma was broken, the central law was broken so really laws there are no absolute laws. **(CE-AV: Falsifiability):** You may be surprised how exceptions may were central laws, dogmas, theories may be broken and you should be open-minded to this.

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
		happened when the central dogmas were broken. I will give you another example for so many years scientists thought that enzymes that give function are proteins Ok. Then decades after that we discovered that RNA actually can give like enzyme- like structures, they can give functions and this is a huge field now just to give you ideas to simplify things nothing is even laws can be broken, central dogmas can be broken. Most of the time they're correct but if you make a discovery that breaks this central dogma, this law, make sure to have enough evidence to support it and to be objective as much as possible.		The biggest discoveries happened when the central dogmas were broken. I will give you another example for so many years scientists thought that enzymes that give function are proteins Ok. Then decades after that we discovered that RNA actually can give like enzyme-like structures, they can give functions and this is a huge field now just to give you ideas to simplify things nothing is even laws can be broken, central dogmas can be broken.
	So, do you agree with science being a social system?	Yes, it's very interactive. It's, there is nothing fixed. Yes. Social you mean, I am not a social scientist, social you mean is something that may change, that may vary right? Yes, there are more or less laws like in general DNA gives RNA and that gives proteins but sometimes this might be broken but we know that DNA and RNA are the genetic material. We know that DNA is the absolute but some organisms can have RNA so there are exceptions to big laws.	**(CE-SK: Scientific Knowledge):** there are more or less laws like in general DNA gives RNA and that gives proteins **(CE-AV: Exceptions to rules):** sometimes this might be broken	**(CE-AV: Exceptions to rules):** DNA is the absolute but some organisms can have RNA so there are exceptions to big laws. **(CE-SK: Scientific Knowledge):** we know that DNA and RNA are the genetic material

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
FM-P4	So, you think politics does influence science?	Definitely. But did you get the idea how funding became because it is an important aspect. In developed countries funding is structured. As you're developing your career to become a scientist, you graduate with a certain degree and then you do something called a you have to go to a doctorate. And by going to a doctorate, you are working with somebody to learn the methodology of producing an output or a thesis but this thesis is quite affected, it's quite a bit of independent work, but is quite a bit affected by your sponsor and the institution you are in. Then in most cultures in the WEST like Europe and America and it is the same in Japan and other developed countries, it is to become an established scientist you have to produce your own area and prove that you can contribute in that particular area. Once you do, and you start teaching that area you will get the title of a professor not an assistant professor so there is a period between your graduation and that which is a minimum of 10 years and it can go on a little bit to 15 years after which in the US they tell you we're not going to invest anymore in you, you can make your money. But if you continue to produce then they continue to invest. The investments let's say you took the PhD degree, when you want to complete a post-doctoral you are working in a lab of	**(SI-Financial systems/Funding):** In developed countries funding is structured **(SI- Social organizations and interactions):** As you're developing your career to become a scientist, you graduate with a certain degree and then you have to go to a doctorate. And by going to a doctorate, you are working with somebody to learn the methodology of producing an output or a thesis but this thesis is quite affected, it's quite a bit of independent work, but is quite a bit affected by your sponsor and the institution you are in. **(SI-Professional activities/ Seeking funds):** you can become independent then you are asked to start putting down proposals for funding. **(SI- Professional activities):** The scientist like any other human being working in any place across the world, you have to reach to a stage when you become independent.	**(SI- Social organizations and interactions):** in most cultures in the WEST like Europe and America and it is the same in Japan and other developed countries, it is to become an established scientist you have to produce your own area and prove that you can contribute in that particular area. **(SI- Social organizations and interactions):** Once you do, and you start teaching that area you will get the title of a professor not an assistant professor so there is a period between your graduation and that which is a minimum of 10 years and it can go on a little bit to 15 years after which in the US they tell you we're not going to invest anymore in you, you can make your money. **(SI- Social organizations and interactions):** The investments let's say you took the PhD degree, when you want to complete a post-doctoral you are working in a lab of somebody or with somebody so the funding you get is basically a stipend for

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
		somebody or with somebody so the funding you get is basically a stipend for your salary plus a little bit that your sponsor will get for using the lab or whatever material you use. As you start developing your own and so on and so forth, usually this takes after your PhD about 3years and it can be 2-4,or 5. After this period of time, you established yourself. The sponsor knows that you are capable of reaching into the independency, and this is why institutions give you without much a do if you want to continue with that career something called an assistant professorship. The assistant professorship by definition you are assisting somebody so most of the money is being generated through funds by the professor OK but you are having the chance to become independent. Three years after the assistant professorship, in general 3, 4, 2, three years after the assistant professorship you are evaluated if within 3 to 4 years you can become independent, you can become independent then you are asked to start putting down proposals for funding. In America if you become funded OK and the NIH will call this an RO1 which a career development fund, if you get your own RO1 for your own subject OK once you get it and usually this is between 5 to 7 years after your assistant professorship, then you become		your salary plus a little bit that your sponsor will get for using the lab or whatever material you use. As you start developing your own and so on and so forth, usually this takes after your PhD about 3years and it can be 2-4,or 5. After this period of time, you established yourself. The sponsor knows that you are capable of reaching into the independency, and this is why institutions give you without much a do if you want to continue with that career something called an assistant professorship. **(SI- Social organizations and interactions):** The assistant professorship by definition you are assisting somebody so most of the money is being generated through funds by the professor OK but you are having the chance to become independent. Three years after the assistant professorship, in general 3, 4, 2, three years after the assistant professorship you are evaluated if within 3 to 4 years you can become independent **(SI- Social organizations and**

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
		tenured in an institution. What does this mean, it means that you can now totally support yourself. As an assistant, a professor is getting funds and you are being supported by his/her funds. As an associate professor you are supporting yourself, if you have, what are the resources of support for a researcher in a university? The institution supports the part when you are an assistant OK as an associate NO but it gives you some support through your teaching you are renumerated through teaching. The scientist like any other human being working in any place across the world, and this concept we don't have it in Lebanon and in countries that didn't reach development yet, because we stay attached to our families, yet in the WEST and developed EAST you have to reach to a stage when you become independent so you are a kid you are supported by your parents, you reach to a stage where you can support yourself then you reach to a stage where you support your children OK this is life. Science is the same, in everything in industry it is the same in America. There is a point in time where you become totally independent.		**interactions):** In America if you become funded OK and the NIH will call this an RO1 which a career development fund, if you get your own RO1 for your own subject OK once you get it and usually this is between 5 to 7 years after your assistant professorship, then you become tenured in an institution. it means that you can now totally support yourself. As an assistant, a professor is getting funds and you are being supported by his/her funds.As an associate professor you are supporting yourself. **(SI- Social organizations and interactions):** The institution supports the part when you are an assistant OK as an associate NO but it gives you some support through your teaching you are renumerated through teaching **(SI- Professional activities):** Science is the same, in everything in industry it is the same in America. There is a point in time where you become totally independent.

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	So, is it similar to describing science as a social system?	I am explaining to you how it is in parallel with the social system. How does this happen? You cannot support all your; some people can support all their requirements and needs from research and how do they prove that they can because they get funds, competitive funds; not funds from their parents or political affiliations. The peers review in America and evaluate the proposed project as good, then this project you say I want to spend10% from my time working on it and post-doctoral fellow to spend all his/her time on it and maybe I want an assistant if I am a professor, an assistant professor to spend 30% of his/her time on it OK so I want their salary and the expenses. The university takes, when NIH or when the NSF funds, scientist cost includes salaries for people working (post-doctoral fellows, assistant professors, research assistants), lab facility, equipment, supplies and trips to attend conferences, costs of publication. This is the cost of a scientist, the investment that the NIH would put. The university gives you the facility and it is running the facility like water, electricity…, it is doing the purchasing for you of materials, The university have a structure similar to an industry. The university is doing something for you collectively it is called overhead so when funding agencies give money from	**(SI-Professional activities/ Seeking funds):** some people can support all their requirements and needs from research and how do they prove that they can because they get funds, competitive funds; not funds from their parents or political affiliations. **(SI- Social certification and dissemination of scientific knowledge/ Peer review process):** The peers review in America and evaluate the proposed project as good **(SI- Financial systems/ Funding):** The university takes, when NIH or when the NSF funds, **(SI- Professional activities/ Attending conferences, publishing findings):** scientist cost includes salaries for people working (post-doctoral fellows, assistant professors, research assistants), lab facility, equipment, supplies and trips to attend conferences, costs of publication. **(SI- Financial systems/ Funding):** As you become independent, the university is taking overhead, you are taking the salaries of all those working with you, and you are taking supplies and everything. **(SI- Social value/ Economic development):** After World War II America saw science as an asset (The atom for peace project). Once you start producing, how did the government know that you are doing an asset? The government monitors how the tax is	**(SI- Financial systems/ Funding):** This is the cost of a scientist, the investment that the NIH would put. **(SI-Financial systems/ Funding):** The university gives you the facility and it is running the facility like water, electricity…, it is doing the purchasing for you of materials, The university have a structure similar to an industry. The university is doing something for you collectively it is called overhead so when funding agencies give money from developed countries they give the institution overhead so you are costing the university nothing. **(SI-Financial systems/ Funding):** once you become independent, you are now an associate professor with tenure and when you (your project) start funding an assistant professor then you become a professor. **(SI- Social organizations and interactions):** You are developing your independence under the supervision of a professor or an associate

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
		developed countries they give the institution overhead so you are costing the university nothing. The American System is different from the European system even though the American system evolved from the European model, the first started in Germany. As you become independent, the university is taking overhead, you are taking the salaries of all those working with you, and you are taking supplies and everything. Why is this important in America? It's important because you don't have to take anything from anyone. The university gets its finance from student tuition. In America, you can't use the tuition for anything but to teach students. A little bit of the research is within the tuition. When you put the tuition, you have to consider the cost of a student from teachers to space to libraries to other facilities and based on that the tuition of the university is determined. From this tuition you can delegate part of it (5-10%) for research. In the past decades, they used to make a lot of labs within the university, now the trend shifted to you go work in a lab. So, the bulk of the research has to develop by itself. After World War II America saw science as an asset (The atom for peace project). Once you start producing, how did the government know that you are doing an asset? The government monitors how the tax is increasing from what is	increasing from what is produced (for instance a certain product) and being sold. Products that were produced evolved with time to become smaller in size and more efficient (example transistor-chips-computers). All this improved the tax revenue for the government. **(SI- Professional activities/ Patent):** as a scientist you patent your innovation so anyone who will use it, they have to pay for you. **(SI- Social value/ fullfill need):** you will be paid from people who are need for this patent and want to use it. **(CE-AV: Objectivity/ Bibliometrics):** in Europe you have no peers, to eliminate subjectivity among peers they developed something called bibliometrics for the evaluation process. They look at citations, how many people have cited you or if you are a senior person, they developed measures to measure the value of your work example impact factor for the journal is dependent on how many times the journal is cited so if you publish in that journal then your article is likely to be cited more definitely you compare people in the same discipline. Impact factor includes many different indicators as well.	professor as a post-doc fellow as an assistant professor under professor, you become independent you become associate professor, when you start funding others. In most universities, you have 7 years to do that and in case you cannot fund projects that will fund you and the assistant professor, you will never make it to professorship. This is called up or leave and they do this to give you time to work. **(SI- Professional activities):** NSF, NIH and the different associations all use the same methodology and use peers to evaluate you not experts, peers that work in the same field and they are benefiting from your work. **(SI- Social certification and dissemination of scientific knowledge):** Skills and attitude are measured much better in peer-revision than it is done in bibliometrics.

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
		produced (for instance a certain product) and being sold. Products that were produced evolved with time to become smaller in size and more efficient (example transistor-chips-computers). All this improved the tax revenue for the government. We can consider the technology of the pandemic as an example. How was the American government capable of producing the COVID vaccine in this short period of time? Usually, it takes more than a year but How? They were working on AIDS. They reached a certain point and didn't proceed then the pandemics of SARS I and SARS II which killed a lot yet didn't spread a lot because the virus killed itself. NIH have records of scientists who worked on AIDS and SARS and where did they reach? They called them, brought them to the lab, and offered them the lab, supplies and money in order to find the vaccine. The first step to find the vaccine is to determine the DNA or RNA sequence of the virus. It took them 2 weeks to identify the sequence while in the past years it used to take 10 to 20 years. You have scientists who are present in their education, skills, attitude, and can plan effectively. That's why nowadays in education we talk about competencies. They found the sequence and then tried to do what they did with AIDS so they were successful and quick. For America		

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
		that invested in the vaccine, its profit increased billion times more than the expenses that were put (so huge sums of money) so the government benefited from the taxes and you have approved budgets and as a scientist you patent your innovation so anyone who will use it, they have to pay for you. After around 10 years it becomes public. And you can also sell a patent for certain companies who will take over selling your patent. So, you will be paid from people who are need for this patent and want to use it. In finance itself there is quiet a bit of science allocation. So, once you become independent, you are now an associate professor with tenure and when you (your project) start funding an assistant professor then you become a professor. To sum up 1. You are developing your independence under the supervision of a professor or an associate professor as a post-doc fellow as an assistant professor under professor, you become independent you become associate professor, when you start funding others. In most universities, you have 7 years to do that and in case you cannot fund projects that will fund you and the assistant professor, you will never make it to professorship. This is called up or leave and they do this to give you time to work. NSF, NIH and the different associations all use the same methodology		

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
		and use peers to evaluate you not experts, peers that work in the same field and they are benefiting from your work. In Europe it is different, you have two things unlike America. In America you don't pay for peers its volunteering, institutions can pay the travel expenses for those peers yet in Europe you have no peers, to eliminate subjectivity among peers they developed something called bibliometrics for the evaluation process. They look at citations, how many people have cited you or if you are a senior person, they developed measures to measure the value of your work example impact factor for the journal is dependent on how many times the journal is cited so if you publish in that journal then your article is likely to be cited more definitely you compare people in the same discipline. Impact factor includes many different indicators as well. In Europe they took the bibliometrics and concentrated on them more than peer-revision which is still primitive. Skills and attitude are measured much better in peer-revision than it is done in bibliometrics.		

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
	Do you think that science with all its different disciplines use the same scientific method?	Very simple. I will tell you a personal experience. When I was an MD and went to Hopkins as a post-doctoral fellowship in pharmacology 90% was research, I told them I want to do a PhD so they told me no you already have an MD. Prove yourself in the lab. Accumulating degrees is useless. At that time there were differences in disciplines but back then I realized that this difference isn't there it's about the humans and their brain when they work all together the discipline moves. I later went to Colombia in Biochemistry so I believe there are tremendous similarities and its about your interest and skills that will give you the title to be in this discipline or not.	**(CE-SM: Reasoning strategies):** At that time there were differences in disciplines but back then I realized that this difference isn't there it's about the humans and their brain **(SI-Social organizations and interactions):** when they work all together the discipline moves.	
FHS-P2	How do you think of scientific models? Are they forms of scientific knowledge or you think of them as being tools to understand the world?	What do you mean by scientific model? ***It can be the model of the machine that you are working on, the model of the human body.*** Mmm, for me scientific models are like the base or in my understanding, in my domain, when we use a model, we it's like I am going to call it a template let's say. It's a collection of data from different backgrounds, from various sources that have been merged together to give a model that is a representative of a certain let's say brain form, phenomenon and using this model will be as a basis, as a reference for you. So whenever you are working on a certain topic,	**(CE-SK:Scientific Knowledge):** scientific models are like the base, I am going to call it a template. **(CE-AV:High confirmation):** whenever you are working on a certain topic, you will have to go back and compare your data to the data of that model **(CE-SP: Data collection):** a collection of data from different backgrounds, from various sources **(CE-SK:Scientific Knowledge):** that have been merged together to give a model that is a representative of a certain let's say brain form, phenomena	

Participant code	Questions	Answer	Analysis	Comments (Repetition / Emerging themes)
		you will have to go back and compare your data to the data of that model. It's the reference let's say of your work.		
	You agree with one of the items on the questionnaire which is "There is a universal scientific method that all scientists use all over the world", yet you disagree with: "All scientific disciplines such as biology, physics, or chemistry use the same scientific method". Can you elaborate?	Yes, there is one scientific way to work for all the domains yet every single domain has its own way around that method. It's let's say it's the basics are going to be the same yet the way you approach it is going to differ. For example, you might go from the general part to the most-specific part or you might go from the smallest part to the general. So, it depends if you are a physicist and working on let's say nuclear medicine or you will go from the atom to the bigger part. If you are a doctor, a medical doctor, you would go from the general and then try to focus to find the source of.	**(CE- SP: Scientific Practice):** there is one scientific way to work for all the domains **(CE-SM: Reasoning strategies):** the basics are going to be the same yet the way you approach it is going to differ	**(CE- SP: Scientific Practice):** every single domain has its own way around that method **(CE-SM: Reasoning strategies):** you might go from the general part to the most-specific part or you might go from the smallest part to the general **(CE-SM: Reasoning strategies):** if you are a physicist and working on let's say nuclear medicine or you will go from the atom to the bigger part. If you are a doctor, a medical doctor, you would go from the general and then try to focus to find the source of.

Table D 3
Qualitative Data Coding of Question Set 3

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
Q1: Do you integrate social or cultural aspects of science in your teaching?	FAS	FAS-P5	Sure. I work in ground water so definitely first of all to increase the awareness about ground water we need to look at it from a society point of view. I need to give them ownership over whatever science we are doing; it's not just solving equations and how this is flowing etc. we have to relate it to something in their environment. Even when I teach geological concepts, I relate to something in the environment because it's important for them to connect to it collectively rather than to see it as something that is just dedicated for an elite. Science is not just for elites I think but it depends how you convey it, it would be targeted for elites or, it's around you science after all.	**(SI- Social values/ Social Awareness):** I work in ground water so definitely first of all to increase the awareness about ground water we need to look at it from a society point of view. **(SI-Scientific ethos/Mertonian norms-communalism):** give them ownership over whatever science we are doing **(CE- SM: reasoning strategies):** it's not just solving equations and how this is flowing. **(SI- Social values):** we have to relate it to something in their environment. **(SI- Political power structures-ideological influences):** it's important for them to connect to it collectively rather than to see it as something that is just dedicated for an elite.	**(SI- Social values):** Even when I teach geological concepts, I relate to something in the environment **(SI- Political power structures-ideological influences):** Science is not just for elites I think but it depends how you convey it, it would be targeted for elites

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
		FAS-P7	Sometimes, sometimes YES. I mention lot of lot of examples coming from social let's say I can give you an example about when I am talking about water treatment or water consumption so I give always my students examples about how many liters of water you are consuming per day so this is typically social because when you are living in a building as you know we are like in water shortage and scare city in Beirut we are ordering tanks so once the tank arrive to the building and we have to pay this tank so how much each apartment should pay so this is something that is creating problems in Beirut and in other cities so how to overcome these problems it is by basically by applying science, it's by implementing, by putting meters on every reservoir for every apartment and showing numbers by the end of each month how much an apartment consumed water so regardless of having lets say three or four or even six, seven people living in, you might have more consumption for an apartment with two people than an apartment with eight people where they are aware and there is some awareness about water consumption. So, this is a typical example of really social that is entering the social and this is something that is on the dunk of everyone	**(SI- Social value):** when you are living in a building as you know we are like in water shortage and scare city in Beirut we are ordering tanks so once the tank arrive to the building and we have to pay this tank so how much each apartment should pay so this is something that is creating problems in Beirut and in other cities so how to overcome these problems it is by basically by applying science, it's by implementing, by putting meters on every reservoir for every apartment and showing numbers by the end of each month how much an apartment consumed water so regardless of having lets say three or four or even six, seven people living in, you might have more consumption for an apartment with two people than an apartment with eight people where they are aware and there is some awareness about water consumption **(CE-AV empirical adequacy and high confirmation):** everything is metered and evidence-based. **(CE-SP- Collecting Data):** We have numbers, we have EXCEL sheets and they are sent to the WhatsApp group of the building so everyone knows exactly its consumption	**(SI- Social Values):** the same thing with electricity as well; how much you are consuming electricity why? Because when you consume electricity now, there is a meter now right? The meter by the private generator that are providing power so if you are using three times more water in an apartment than in another apartment so this apartment is consuming three times more electricity than the other one to have the water pump it to the top of the building so this apartment has to pay three times more than the other one for the generator so this is what I am implementing in my building. It happens that I am the president of the association of the building and people now understood very well how I am implementing science and my knowledge in science to merge it to improve yes to improve social and to avoid problems between neighbors.

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			especially in these criteria in Beirut where there is water scare city. It is the same thing with electricity as well; how much you are consuming electricity why? Because when you consume electricity now, there is a meter now right? The meter by the private generator that are providing power so if you are using three times more water in an apartment than in another apartment so this apartment is consuming three times more electricity than the other one to have the water pump it to the top of the building so this apartment has to pay three times more than the other one for the generator so this is what I am implementing in my building. It happens that I am the president of the association of the building and people now understood very well how I am implementing science and my knowledge in science to merge it to improve yes to improve social and to avoid problems between neighbors. So now there is no problems anymore because everything is metered and evidence-based. We have numbers, we have EXCEL sheets and they are sent to the WhatsApp group of the building so everyone knows exactly its consumption etc., how much he has to pay or she has to pay so it's really a nice experience.		

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
		FAS-P12	A little bit. You know, so one thing that I try to tell my students not to consider any single scientific paper as the truth right even though they are all represented that way but an understanding emerges gradually and iteratively so that's, I think that's where this aspect, and I see this mistake repeatedly in in among students that they always think Ok that the latest paper tells us how it is. No. It's you have look at, to think of the possible shortcomings and that became particularly apparent during the pandemic where I think for the broader public at large people were frustrated where the case fertility rate estimates were fluctuated by two orders of magnitude. Scientists don't know. It is an iterative process. There is not one study that tells you how it is it's over time the collective endeavor with the back and forth makes the real thing emerge so I try to tell them that but I think it also requires more experience in order to internalize that.	**(CE- AV Falsifiability):** I try to tell my students not to consider any single scientific paper as the truth right even though they are all represented that way **(SI- Social certification and dissemination of scientific knowledge):** but an understanding emerges gradually and iteratively. **(CE-SM- Manipulation of variables):** I think for the broader public at large people were frustrated where the case fertility rate estimates were fluctuated by two orders of magnitude. **(SI- Social certification and dissemination of scientific knowledge):** it's over time the collective endeavor with the back and forth makes the real thing emerge	**(SI- Social certification and dissemination of scientific knowledge):** Scientists don't know. It is an iterative process. **(CE- AV Falsifiability):** There is not one study that tells you how it is it's over time the collective endeavor with the back and forth makes the real thing emerge.
		FAS-P13	I would say YES but perhaps not as much as I want or not as much as I should. But I do integrate it. Often when I speak to the class I give example about science and I also relate to the everyday world and sometimes I also relate to social situations but I don't do it to be honest in a very	**(SI- Social values):** I give example about science and I also relate to the everyday world and sometimes I also relate to social situations **(SI- Social values- public policy/social laws for public good):** a year ago I was involved in a webinar series that the	

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			structured manner. And this is something that you mention it perhaps I should work on structuring it especially that a year ago I was involved in a webinar series that the physics department has organized a series of four seminars about science and public policy. Actually, physics and public policy and I have to say that this webinar although I didn't know much about it ahead of time, I didn't know much about the topic, it was an eye opener to integrate aspects of social science and public policy into the physics curriculum.	physics department has organized a series of four seminars about science and public policy. Actually, physics and public policy and I have to say that this webinar although I didn't know much about it ahead of time, I didn't know much about the topic, it was an eye opener to integrate aspects of social science and public policy into the physics curriculum.	
	FEA	FEA-P1	Ahhh more on the first part probably on the social elements That's quite explicit because in my field I'm a civil engineer; civil and environmental engineer, by the nature if you look at the title civil and environmental engineering social aspects are at the core of them so a lot of the things that we work on are driven by societal needs so it's imperative to bring it on into the classroom the social. The institutional we may I may bring it in reference to how it affects the procedures we go through to design or to construct or whatever facilities that we are thinking of so we may talk about the institutional.	**(SI-Social value- address societal needs):** by the nature if you look at at the title civil and environmental engineering social aspects are at the core of them so a lot of the things that we work on are driven by societal needs. **(SI- Social organizations and interactions):** institutional we may I may bring it in reference to how it affects the procedures we go through to design or to construct or whatever facilities that we are thinking of so we may talk about the institutional.	

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
	FEA	FEA-P8	Well in my teaching there is a lot of evidence-based work, a lot of data collection and then doing analysis on that data so I teach statistics, so that is by nature you know, you collect data and you use that to reach conclusions. Now the social aspects I don't think we discuss that in class no not directly like we are discussing here, I do mention it and at times we never talk about hypothesis testing. I give them examples at times about you know articles like this or that so you always have to check, check the sample-size check: Is it valid? Is it reliable? So, these kinds of things that we do talk about so I could say yes in that case but it's not like the main focus of the course.	**(CE- AV: empirical adequacy):** in my teaching there is a lot of evidence-based work **(CE-SP: Data collection):** a lot of data collection **(CE- SM: Reasoning strategies):** then doing analysis on that data **(SI- Social certification and dissemination of scientific knowledge/ validation and evaluation):** you know articles like this or that so you always have to check, check the sample-size check: Is it valid? Is it reliable?	**(CE-SP: Data collection):** I teach statistics, so that is by nature you know, you collect data and **(CE-SM: Reasoning strategies):** you use that to reach conclusions.

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
	FHS	FHS-P2	Yes. My courses are more basic physics, how X-rays are formed, what are the factors that affect the development of an image and all of these are pure theorems, pure physics, pure knowledge of how things work and sometimes students look at me and think I am talking Chinese so I try to give them real-life examples. One part of the chapter of a course is related to distances, how the distance from the source of the X-ray to the patient will affect the quality of the image so what I try to do for example is tell them to take their phones and open the flashlights and put their hands on the table and move the flashlights up and down and they will see it in front of their eyes how the shadow of their hand is moving when the distances are moving up or down so I try to simplify these kind of information for them and give them real life examples for them to understand	**(CE-SK: Pure knowledge):** My courses are more basic physics, how X-rays are formed, what are the factors that affect the development of an image and all of these are pure theorems, pure physics, pure knowledge of how things work. **(SI- Social Values):** I try to give them real-life examples. **(CE-SP: Making predictions):** how the distance from the source of the X-ray to the patient will affect the quality of the image so what I try to do for example is tell them to take their phones and open the flashlights and put their hands on the table and move the flashlights up and down and they will see it in front of their eyes how the shadow of their hand is moving when the distances are moving up or down	**(SI-Social value/Real-life examples):** give them real life examples for them to understand

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
	FM	FM-P3	What I integrate in my teaching especially that I teach genetic-based courses and cancer-based courses are how genetic diseases or cancers vary worldwide or in different societies. What are the genetic factors that might affect the outcome also environmental factors and this is where in my discipline we call epigenetics are factors that you don't inherit in general these are factors that are affected by our environment and by nurture so genetics is nature, environment is nurture.	**(CE-SP- Making observations and collecting data):** I teach genetic-based courses and cancer-based courses are how genetic diseases or cancers vary worldwide or in different societies. **(CE-SP: Posing questions):** What are the genetic factors that might affect the outcome also environmental factors **(CE-SK: Conceptual knowledge):** we call epigenetics are factors that you don't inherit in general these are factors that are affected by our environment and by nurture so genetics is nature, environment is nurture	
	FAFS	FAFS-P2	Oh ya I have to. ***Can you give me examples?*** I teach, my subject is plant nutrition and soil chemistry. In soil chemistry of course its basics, chemistry basics, like any chemistry course. And then, in plant nutrition again we build the results on the experimentations and then when we get the conclusions and the results how to, most important thing at the end of the course, I want my students to be able to design a fertilization program for different crops like if you are growing apples, you should take a sample of the soil and the plant, analyze these and then recommend to the farmer what he/she should do. If you are having cucumber, it's a different	**(CE-SK: chemistry basics):** In soil chemistry of course its basics, chemistry basics, like any chemistry course. **(CE-SP: Experimentation):** in plant nutrition again we build the results on the experimentations **(CE- SK: Results):** then when we get the conclusions and the results **(CE-SP: Designing experiments):** I want my students to be able to design a fertilization program for different crops like if you are growing apples, you should take a sample of the soil and the plan **(CE-SM: Reasoning strategies):** analyze these **(CE-SM: Manipulation of variables):** If you are having cucumber, it's a different	

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			story. If it's parsley, if it's lettuce so every crop have something and then from there we have to go to the economics of it, of not only producing higher yield, is it economical to go to the highest yield? And then, livelihood of that producer, the farmer, and how much that farmer would make money out of it and from there how we go to food security, and should like an example should we grow wheat or strawberries. We have to put. Farmers would make more money from strawberries, but wheat is more needed for the humans, so we discuss issues like that Ok.	story. If it's parsley, if it's lettuce so every crop have something. **(SI- Financial systems/ economy and yield):** from there we have to go to the economics of it, of not only producing higher yield, is it economical to go to the highest yield? **(SI- Social value/liveihood):** livelihood of that producer, the farmer, **(SI- Financial systems/ Money):** how much that farmer would make money out of it. **(SI- Social value/ food security):** from there how we go to food security, and should like an example should we grow wheat or strawberries	
		FAFS-P4	Yes, I do, I do because as I told you knowledge on its own may not be translated so you need to have, to know how you can translate this scientific knowledge into the community and that's why you need to understand you know the eating behavior for example: Why do you eat? Why do you think about this? Ya, so it makes life different.	**(CE-SK: resultant knowledge):** I told you knowledge on its own may not be translated **(SI- Social value):** so you need to have, to know how you can translate this scientific knowledge into the community **(CE- SP: Posing questions):** you need to understand you know the eating behavior for example: Why do you eat? Why do you think about this?	**(SI- Social value):** Ya, so it makes life different.

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
Q2: Do you think that the science curriculum should not only cover scientific knowledge but also the social and cultural aspects of science?	FAS	FAS-P5	Definitely, it has to be able to serve society, some aspects of it because we don't have to dilute it. If I teach water and I only tackle the aspect of management, I am not giving them science since they need to be expert enough in the theoretical things to be able to come up with science evidence, development. So, I think we have to show the importance of getting expertise in this science so that they can make an impact and work on small scale trying to figure out how they have small impacts until they are well rounded with the science itself and they can produce a larger impact on society.	**(SI-Social values/ societal benefit):** it has to be able to serve society, some aspects of it because we don't have to dilute it. **(CE-SK: theoretical things):** since they need to be expert enough in the theoretical things **(CE- SP: designing experiments to produce knowledge):** to be able to come up with science evidence.	**(SI- Social value/ impact on society):** work on small scale trying to figure out how they have small impacts until they are well rounded with the science itself and they can produce a larger impact on society.
		FAS-P7	Definitely, definitely. In my teaching experience, even if I am teaching, for example I teach Chemistry 202 which is Introduction to Environmental Chemistry for engineering students and you are talking about atmospheric pollution, about water pollution, water treatment, how to avoid atmospheric pollution etc. what are the pollutants yes, I give them real examples, how these examples are affecting our life, our social life even with each other. ***Do you think that they engage with the material better?*** Oh definitely, you cannot imagine their eyes, how their eyes are really shining when I am talking about	**(CE- SK: pure knowledge):** you are talking about atmospheric pollution, about water pollution, water treatment, how to avoid atmospheric pollution etc. what are the pollutants. **(SI-Social value: improve quality of people's life):** I give them real examples, how these examples are affecting our life, our social life even with each other. **(SI- Financial systems/ funding):** funding agencies are emphasizing on these things. **(SI- Professional activities: applying for a grant and writing proposals):** we applied also for this grant, the Department of Chemistry with the Department of	**(SI-Social value: improve quality of people's life):** let's say BLISS STREET for example the particulate matter in the atmosphere at BLISS STREET are 10 times more than the particulate matter in our campus in the atmosphere so don't spend time on BLISS smoking and etc. rather stay on campus because you are breathing healthier yes. **(SI-Social value: improve quality of people's life):** there are many other examples about let's say the ozone that is produced at the ground state level which is an irritating gas and how can we reduce let's say ozone

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			for example simple information about let's say BLISS STREET for example the particulate matter in the atmosphere at BLISS STREET are 10 times more than the particulate matter in our campus in the atmosphere so don't spend time on BLISS smoking and etc. rather stay on campus because you are breathing healthier yes. And also, there are many other examples about let's say the ozone that is produced at the ground state level which is an irritating gas and how can we reduce let's say ozone emission or if you want to get some bread from a store close to you, please go by walking and don't use your car etc. so there are lot and lot and lot of examples that can show and students are really aware about it. And always I ask them questions and I told them, I tell them please go back home and ask your parents because they don't have for example any idea about the example: how many liters of water we are consuming per day in our apartment, they don't even know for example what is the volume of the reservoir that they have on the top of the building, they have no clue about it. So from here we can notice for example we can notice that the funding agencies are emphasizing on these things. The USAID in Lebanon launched already a call about	Education with the Department of Hydrogeology and we submitted a proposal, a very strong proposal about how to spread this awareness among young people in schools and from schools to the community where they are living so we are waiting	emission or if you want to get some bread from a store close to you, please go by walking and don't use your car etc. so there are lot and lot and lot of examples that can show and students are really aware about it. **(SI-Social value: improve quality of people's life):** please go back home and ask your parents because they don't have for example any idea about the example: how many liters of water we are consuming per day in our apartment, they don't even know for example what is the volume of the reservoir that they have on the top of the building, they have no clue about it. **(SI- Financial systems/ funding):** The USAID in Lebanon launched already a call about awareness on water conservation and water sanitation in Lebanon through schools at the mid-school level for grades 6-7-and8

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			awareness on water conservation and water sanitation in Lebanon through schools at the mid-school level for grades 6-7-and8. And we applied also for this grant, the Department of Chemistry with the Department of Education with the Department of Hydrogeology and we submitted a proposal, a very strong proposal about how to spread this awareness among young people in schools and from schools to the community where they are living so we are waiting if we will get this one, you will hear about it.		
		FAS-P12	Yes, yes, definitely because I mean especially for people I mean for several reasons: one is like the pandemic is an example where people who were not trained in science, they weren't able to put it in proper context right and so there are sort of these, one reaction is just you know throw it out all together and say science useless or latch on to one particular reside and say all the rest is fake news. How to deal with this? Because suddenly people were watching science happening in real time right which usually people don't you know if you if you if you read a textbook then you get this entire process condensed into these bite size or condensed that that makes it understandable for a student but I think that for me was a good example of	**(SI- Social value/Societal impact of science-related issues):** Because suddenly people were watching science happening in real time right which usually people don't you know **(SI-Professional activities/ Presenting findings):** if you read a textbook then you get this entire process condensed into these bite size or condensed that that makes it understandable for a student **(CE-SP: Processes of inquiry):** I think that for me was a good example of why a certain literacy in the process of science and how it works is important to for them. **(CE-SK: knowledge presentation in textbooks):** you were always being told in your undergrad when you read these textbooks that everything is sort of	

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			why a certain literacy in the process of science and how it works is important to for them but then also particular for PhD students who want to become scientists themselves. Masters and PhD students because they struggle with this transition of where, where suddenly you know you were always being told in your undergrad when you read these textbooks that everything is sort of Daddy's known truths and suddenly the bottom of it when things are much more Ya when you have to be the judge too but I think when people try to try to write scientific research themselves they realize how difficult it is to identify even tiny tangible results that they can rely on.	Daddy's known truths. **(SI- Professional activities):** I think when people try to try to write scientific research themselves they realize how difficult it is **(CE-SK/ products of scientific activities):** identify even tiny tangible results that they can rely on.	
	FEA	FEA-P1	Absolutely I think it's, it's a great idea, you get a full perspective on why it helps you answer ask and try to answer a lot of the WHY questions which I think are the core of science WHY	**(CE-SP: Making predictions/ designng experiments/ formulating hypothesis):** you get a full perspective on why it helps you answer ask and try to answer a lot of the WHY	
	FEA	FEA-P8	The curriculum at university level? Yes, I think so. I think it does as far as I know. I think this is very important not just for a scientist but also for people in humanities, social sciences and so on.	**(SI- Social value)** Yes, I think so. I think it does as far as I know (incorporate social and cultural aspect) I think this is very important not just for a scientist but also for people in humanities, social sciences	

Question Set 3	**Faculty**	**Participant code**	**Answer**	**Analysis**	**Comments (Repitition / Emerging themes)**
	FHS	FHS-P2	Sure. Because they go together. As I said before for me social is to try to simplify the scientific knowledge that you have to people that do not understand that kind of science and this is something really hard. I recently went with my wife who is a PhD candidate at the Lebanese University, she is doing literature, French literature, so she participated in a competition and won it here in Lebanon which is to present you thesis in 180 seconds, so they have to talk and explain their thesis in 180 seconds, in 3 min and they should really simplify it for the average normal person to understand it and we represented Lebanon in Montreal in Canada and the topics the way they are represented, for me this is a real science. It's really difficult to simplify and to make it accessible for everyone so including these social sciences and what you said is very important to start from an early age even to try to develop this skill of simplification and I think if you do this exercise, you will not only help people around you to understand but you will also be able to grasp the information better and present it in more user-friendly way.	**(CE-AV: Simplicity):** try to simplify the scientific knowledge that you have to people that do not understand that kind of science and this is something really hard.	**(CE-AV: Simplicity):** I recently went with my wife who is a PhD candidate at the Lebanese University, she is doing literature, French literature, so she participated in a competition and won it here in Lebanon which is to present you thesis in 180 seconds, so they have to talk and explain their thesis in 180 seconds, in 3 min and they should really simplify it for the average normal person to understand it and we represented Lebanon in Montreal in Canada and the topics the way they are represented, for me this is a real science. **(CE-AV: Simplicity):** It's really difficult to simplify and to make it accessible for everyone so including these social sciences and what you said is very important to start from an early age even to try to develop this skill of simplification and I think if you do this exercise, you will not only help people around you to understand but you will also be able to grasp the information better and present it in more user-friendly way.

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
	FM	FM-P3	Definitely, definitely. I know that now with the American Association for Cancer Research, there are sessions devoted to social impacts and how different groups are not affected by advances so there are seminars, there are working groups that highlight the importance of what we call health disparity. How health where therapies or research bypass certain groups such as women, historically weren't studied as much as men even in animal experiments we use male, scientists used to use male rats or male mice not as much female rats or female mice or other animals. So now even in animals we have to pick males females so definitely in science we have to make sure to include different ethnicities, social economic studies.	**(SI-Social organizations and interactions):** I know that now with the American Association for Cancer Research, there are sessions devoted to social impacts and how different groups are not affected by advances **(SI- Professional activities):** so there are seminars **(SI- Political power structures/ Gender):** there are working groups that highlight the importance of what we call health disparity. How health where therapies or research bypass certain groups such as women, historically weren't studied as much as men even in animal experiments we use male, scientists used to use male rats or male mice not as much female rats or female mice or other animals.	**(SI- Political power structures/ Gender):** So now even in animals we have to pick males females so definitely in science we have to make sure to include different ethnicities
		FM	Yes, definitely		
	FAFS	FAFS-P2	Oh, ya definitely. I think in every subject should touch on that not only every course by itself. The application of the findings.	**(SI- Social value):** The application of the findings.	
	FAFS	FAFS-P4	Yes, I think science should either support them or say this social and institutional thing they don't make sense you know because sometimes there are certain things that people believe in sometimes, they are wrong so I think the beauty of the science is to explain to the people, you know part	**(CE-AV: Providing explanantions):** I think the beauty of the science is to explain to the people, you know part of it, is to clarify whether you know, whether things in society is correct or not and need to be changed.	

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			of it, is to clarify whether you know, whether things in society is correct or not and need to be changed		
Q3: Do you think that it makes a difference to students' learning of science if they engage in discussions about experimental data, or how knowledge develops in science?	FAS	FAS-P5	Sure, we have a lot of examples where we had certain theories that we have adopted for a long period of time and then later on came some rebuttals and it was proven that this is not the case. For instance, I can give the example of plate tectonics where we couldn't find until 1960 why was this happening so it is important because it will allow them to know that nothing is set, it's true based on I have a hypothesis, I developed a series of data that is more likely to guide me through this but there is the counter argument that no body has proven yet. So even the most scientific theories that we have, they have consensus from science people but it doesn't mean that these are the only ways or they are effective on all the domains or they are effective at all the scales etc. or they are happening at the same rate. So, this will allow us, allow them to have this incentive to debunk a certain theory or to really prove it again or to reproduce data, not to take things for granted. Reproducibility is very important. This gives them empowerment, not everything that is said to you is correct even if science sometimes.	**(CE-SK: Scientific Knowledge/ Theories):** we had certain theories that we have adopted for a long period of time **(CE-AV: Falsifiability/ Rebuttals):** later on came some rebuttals and it was proven that this is not the case. **(CE-SP: Formulating a hypothesis):** I have a hypothesis, **(CE-SP: Data collection):** I developed a series of data that is more likely to guide me through this. **(SI- Social certification and dissemination of scientific knowledge):** So even the most scientific theories that we have, they have consensus from science people **(CE-AV: Reproducibility):** or to really prove it again or to reproduce data, not to take things for granted **(CE- SM: Reasoning strategies):** when they derive something, I don't give them directly the solution of this of a certain equation. They have to derive it, they have to look whether this applies, where it doesn't apply. **(CE-SM: Maniplation of variables):** We work a lot on scales we see that we have these numbers at this small scale and then	**(CE-AV: Falsifiability/ Nothing is set):** I can give the example of plate tectonics where we couldn't find until 1960 why was this happening so it is important because it will allow them to know that nothing is set **(CE-AV: Falsifiability/ Nothing is set):** but it doesn't mean that these are the only ways or they are effective on all the domains or they are effective at all the scales etc. or they are happening at the same rate **(CE-AV: Falsifiability/Debunk a theory):** allow them to have this incentive to debunk a certain theory **(CE-AV: Reproducibility):** Reproducibility is very important. **(CE_AV: Falsifiability):** not everything that is said to you is correct even if science sometimes. **(CE-SM: Manipulation of variables):** You have the challenge of time and the challenge of space.

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			Do you convey this to your students? I do, sometimes when they'll have to; when they derive something, I don't give them directly the solution of this of a certain equation. They have to derive it, they have to look whether this applies, where it doesn't apply. We work a lot on scales we see that we have these numbers at this small scale and then I show them that if you go at a bigger scale, you will have another representative volume so you will have other numbers. So, it is really important to know these challenges; especially in geology. You have the challenge of time and the challenge of space. And you have a lot of flexibility in this but you shouldn't always use your flexibility. It's important for them to know the limitations, the error, uncertainty is very important. If they don't do this, they feel that everything taught to them is correct.	I show them that if you go at a bigger scale, you will have another representative volume so you will have other numbers. So, it is really important to know these challenges; especially in geology. **(CE-SP: Experimentation):** It's important for them to know the limitations, the error, uncertainty is very important	
		FAS-P7	One of the drawbacks that we have with this new generation of students is the data treatment, and the, so how to, how to comment on the data and analyze it, so there is some if you want, there is some weakness in the data analysis and this is what I am trying in fact to do in my teaching when I teach for example the analytical chemistry laboratory so there is	**(CE-SM: Reasoning strategies/Analysis):** One of the drawbacks that we have with this new generation of students is the data treatment, and the, so how to, how to comment on the data and analyze it **(CE-SK: Resultant knowledge):** every time you have a result, so this result should have like an uncertainty it's not	**(CE-SM: Reasoning strategies/Analysis):** there is some weakness in the data analysis **(CE-SM: Reasoning strategies/Analysis):** the analytical chemistry laboratory so there is a big part on the data treatment, data analysis, statistical approach

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			a big part on the data treatment, data analysis, statistical approach etc. so how I am trying to tell students that every time you have a result, so this result should have like an uncertainty it's not 100% certain so you have to determine uncertainty on this result, you have to reproduce this result and you cannot provide a result without an uncertainty, without, because finally if you are working later on in an analysis lab so the public will receive a result but not the method how you did the analysis because they don't care about this. There is a result let's say 10 plus or minus, it's 10, no it's not 10 it's10 plus or minus an uncertainty because sometimes the uncertainty might play a major role in decision maker especially when it comes to judges etc. if you have like a fire or so the, the forensic science comes and takes samples etc. so this is very important.	100% certain so you have to determine uncertainty on this result **(CE_AV: Reproducibility and empirical adequacy):** you have to reproduce this result and you cannot provide a result without an uncertaint **(SI- Professional activities: Presenting findings and providing explanations):** the public will receive a result but not the method how you did the analysis because they don't care about this **(SI- Social value/ decision makers):** the uncertainty might play a major role in decision maker especially when it comes to judges	
		FAS-P12	I try it's hard it takes time and there is a reason why textbooks condense all that knowledge you know distill it into just the factual results because then you can you know you can spend a lot of time just learning the facts and the facts are important too and especially biology which is this vast collection of diversity of facts because biology has this extreme	**(CE-SK: factual knowledge):** there is a reason why textbooks condense all that knowledge you know distill it into just the factual results **(CE- SP: processes of inquiry):** spending time on the process for finding it out takes time away from learning the facts **(SI- Professional activities/ Attending seminars):** I think it is best done in a	**(CE-SK: factual knowledge):** you can spend a lot of time just learning the facts and the facts are important too and especially biology which is this vast collection of diversity of facts because biology has this extreme built in diversity. **(CE-SK: factual knowledge):** you can spend ten years just learning

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			built in diversity and so you know you can spend ten years just learning about some processes in the cells, if you learn about other molecules and all the interactions, so you always have to find a balance between the huge collection of facts and if students know all these facts, that's really helpful and spending time on the process for finding it out takes time away from learning the facts so it's always it's a trade of and generally in courses I try to I try to bring this into my courses but I think it is best done in a seminar where you read actual primary research papers.	seminar where you read actual primary research papers.	about some processes in the cells, if you learn about other molecules and all the interactions, so you always have to find a balance between the huge collection of facts and if students know all these facts, that's really helpful
		FAS-P13	Oh yes 100%. It is good that you mentioned it and we are in my office. One of the most interesting books I have read over the years is this one "Physics the Human Adventure" Okay it is basically the history of physics that can be used to teach a course in physics through the history and how the ideas of physics have evolved over the centuries. I have to say that I never had the time to do it but this is one thing that I would really like to teach, teaching physics through its history and I think it will be very beneficial for the students and they will understand far more if they say the evolution of ideas as opposed to stating a fact like light is described as a series of a packet of	**(CE- SK: knowledge in a physics course):** it is basically the history of physics that can be used to teach a course in physics through the history and how the ideas of physics have evolved over the centuries.	**(CE-SK: knowledge in a physics course)** they will understand far more if they say the evolution of ideas as opposed to stating a fact like light is described as a series of a packet of photons for example.

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			photons for example. ***Do you engage them in such discussions about experimental data, or how knowledge develops in science?*** I do as much as I can. The problem is that often in our physics courses, the curriculum is so large in the courses that it gives us, it doesn't give us enough room to discuss these issues that are somehow seen outside of the curriculum, of the syllabus of the course. That's why if we structure and we integrate them in the course we will be able to manage our time differently.		

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
	FEA	FEA-P1	YEAH, well definitely engaging in conversations like this for students is good because on on on one hand it will get them to think about these ground aspects but also on the other hand to hear other perspectives and unless you have conversations with others you are not going to have another perspective we tend to reinforce our own beliefs and ways of understanding things if we just rely on us with this looking at the computer and reading from the screen whereas when I engage in conversation with someone else I may I may get things a little bit differently. ***Do you often engage them in such discussions?*** Conversations. Not as much as I should Not enough ***Why?*** I think you know the answer like everyone is busy, everyone is trying to move forward, time is of essence. You look at your calendar and you see very little time slots available so Very frank answer.	**(CE-SK: foundations):** on one hand it will get them to think about these ground aspects. **(SI- Scientific ethos/ Respect for colleagues and openess):** on the other hand to hear other perspectives **(SI- Scientific ethos/ Caution against bias):** we tend to reinforce our own beliefs and ways of understanding things if we just rely on us with this looking at the computer and reading from the screen	**(SI- Scientific ethos/ Respect for colleagues and openess):** whereas when I engage in conversation with someone else I may I may get things a little bit differently.

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
	FEA	FEA-P8	I do touch on it yes as I said when we talk about hypothesis testing, reliability, validity, these types of things you touch on them. Several times I mention things about you need to make sure that it is reliable, valid, you need to question, you need not to take things because of its value, you need to make sure from where these conclusions are coming so yes I do mention such things.	**(CE-SP):** hypothesis testing **(CE-AV:empirical adequacy):** reliability, validity	**(CE- AV: empirical adequacy):** I mention things about you need to make sure that it is reliable, valid, you need to question, you need not to take things because of its value, you need to make sure from where these conclusions are coming
	FHS	FHS-P2	Discuss the experimental data Yes. How it changed or evolved with time I guess less but yes it can be useful. Always engage them in a discussion to try to I put these the I raise a question and give them enough information for them to come out with a result, with a certain conclusion and based on this conclusion I would tell them if they did it correct or wrong and try to explain where did they go wrong with their explanation. I try to guide their discussion for them to find the correct answer. But I always like them to give or discover the answer rather than me giving them the answer. I think it's a better way for them to improve their critical thinking, their analysis skills.	**(CE-SM: Reasoning strategies):** I raise a question and give them enough information for them to come out with a result, with a certain conclusion and based on this conclusion I would tell them if they did it correct or wrong and try to explain where did they go wrong with their explanation.	**(CE-SM: Reasoning strategies):** I always like them to give or discover the answer rather than me giving them the answer. I think it's a better way for them to improve their critical thinking, their analysis skills.

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
	FM	FM-P3	Yes definitely. In my teaching I always rely on the interaction with the students and I always ask their opinion. Definitely students are big part of our scientific whether in the classroom scientific developments or definitely in the lab we rely on our students most of our research is done by students. Our programs here our graduate programs MS PhD and medical programs. So, this is very important. But also, I would like to emphasize the input of our graduate students, also very important	**(CE-SP: Processes of inquiry):** students are big part of our scientific whether in the classroom scientific developments **(SI- Social organizations and institutions/ Lab):** definitely in the lab we rely on our students most of our research is done by students. **(SI- Social organizations and interaction/ University programs):** Our programs here our graduate programs MS PhD and medical programs.	
	FAFS	FAFS-P2	They have to know how science developed with time. You have to read the history of everything and I insist that my students for instance know when oxygen was discovered. They should know, because human being have been breathing since they were الله أعلم you know since life started and oxygen was not discovered till 200 years ago. And that's very important to know that after the discovery of oxygen really biology and other sciences started going, we knew oxidation, we knew and then the things developed and we cannot stop it. Now it's going very, very fast. The good and the bad part of science for humans.	**(CE-SK):** You have to read the history of everything and I insist that my students for instance know when oxygen was discovered.	**(CE- SK):** that's very important to know that after the discovery of oxygen really biology and other sciences started going, we knew oxidation

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
		FAFS-P4	Yes, because you see because we say that all those sciences, we say is a fact or so on but there is like sometime things become more popular at the expense of other things, so there is more attractive line of science and then you could over-ride the other aspect you know. I know one example let's say one example in nutrition in a way so it's like sometime you go to a stage where everybody talk about fiber or everybody talk about anti-oxidant or everybody talk about omega-3 and they really forget that there is really something else so there is like fashion in a way so maybe people they drift and they forget the other aspects of it.	**(CE- SK: factual knowledge):** all those sciences, we say is a fact **(SI- Social value):** I know one example let's say one example in nutrition in a way so it's like sometime you go to a stage where everybody talk about fiber or everybody talk about anti-oxidant or everybody talk about omega-3 and they really forget that there is really something else so there is like fashion in a way so maybe people they drift and they forget the other aspects of it.	
Q4: Do you think that understanding scientific methodology can help students distinguish between science and non-science?	FAS	FAS-P5	Obviously, obviously and there is something that is very straight forward data OK you can start with the hypothesis and this can be intuitive, intuitive depending on the degree of expertise then data then results and then going back to validate again and then going back to identify further data to further validate the model in a way where there could be no other possible interpretation of this specific set of data.	**(CE-SP: Formulating a hypothesis):** you can start with the hypothesis **(CE-SP: Making predictions):** this can be intuitive, intuitive depending on the degree of expertise **(CE- SP: Data collection):** data **(CE-SK: Resultant knowledge):** results **(CE-AV: Empirical adequacy):** going back to validate again and then going back to identify further data to further validate the model in a way where there could be no other possible interpretation of this specific set of data.	

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
		FAS-P7	Oh, ya definitely because when a student is trying to start let's say a project in a lab so there's a hypothesis to put with the advisor and some literature to make sure that the hypothesis is, is a plausible hypothesis to be, to go forward in it and then the planning of the experiments is based also on science knowledge and on the literature where previous students or previous researchers did the experiments and then we will take it from there to continue with it. OK. So of course, definitely what you have said is definitely making students, the student approach of science is based for them on experimentation	**(CE-SP: Formulating a hypothesis):** there's a hypothesis to put with the advisor and some literature to make sure that the hypothesis is, is a plausible hypothesis to be, to go forward in it **(CE-SP: Experimentation):** the planning of the experiments is based also on science knowledge and on the literature where previous students or previous researchers did the experiments and then we will take it from there to continue with it.	**(CE-SP: Experimentation):** the student approach of science is based for them on experimentation
		FAS-P13	I think yes, because when they see how we came up with the scientific ideas and when they see the methodology that we have used they will definitely be more convinced of what is really scientific what have passed the test of the scientific method.	**(CE-SM: Reasoning strategies):** when they see the methodology that we have used they will definitely be more convinced of what is really scientific **(SI- Social certification and dissemination of the scientific method):** what have passed the test of the scientific method.	
	FEA	FEA-P1	What's the first part? Question repeated. YEAH to some extent I think like we started the first question to me science is a process is a methodology so if you really understand that you or able to delegate a little bit more what makes an activity a little bit more scientific.	**(CE-SP: process):** to me science is a process is a methodology	

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
	FEA	FEA-P8	I think so, I think it helps yes especially from an early age, this whole process I think it is a good practice for people in life I always remember that when reading an article about politics I always remember that is this thing evidence-based, if not evidence-based then how are these conclusions reached. So, I definitely think it helps Yes	**(CE-AV: Empirical adequacy/ Evidence-based):** reading an article about politics I always remember that is this thing evidence-based, if not evidence-based then how are these conclusions reached	
	FHS	FHS-P2	Sure, let's take the COVID-19 example. So recently everyone became an expert in COVID-19 so how do you want the students to recognize who is really a professional and who is not. So understanding how things work, understanding the methodology for creating a drug, for creating a vaccine and not say they are injecting us with chips to monitor our everyday activities so they should learn how things really work in order for them to recognize what is correct and what is wrong and for their surroundings, if they are knowledgeable about how things work, they will explain it to their surroundings and we will try to reduce the idiocy.	**(CE-SP: Processes of inquiry):** understanding how things work, understanding the methodology for creating a drug, for creating a vaccine and not say they are injecting us with chips to monitor our everyday activities. **(CE-AV: Providing explanations):** for their surroundings, if they are knowledgeable about how things work, they will explain it to their surroundings	**(CE-SP: Processes of inquiry):** they should learn how things really work in order for them to recognize what is correct and what is wrong

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
	FM	FM-P3	Absolutely. This is a good professor, a good teacher should instigate in the students this scientific development and students should be able to judge, students should be able to question, students should be able to say No this is not correct students should be able to think and this is very important. If we fail as educators to instill this in our students, we have failed in our mission ***Do you use history of science in your teaching?*** HAHA YES. I would love it. Also, I would love to when I go to a lecture for lecturers to give them the history, for instance in my case I show them history of cancer research, how did it start? When was the first time that scientists knew that cancers are made of cells? 200 years ago, scientists didn't know that cancers are made of cells. They thought they're liquids, they though they're dark matter in our body, they didn't know. So, history is very important whether in cancer research or how a scientist developed the methodology, what are the big in any course I teach biochemistry for instance for nursing and for graduate students, I always start my lecture, first lecture, by giving them the biggest discoveries in history. That would give them a feel of the	**(CE-SM: Reasoning strategies):** students should be able to judge, students should be able to question, students should be able to say No this is not correct students should be able to think. **(CE-SK):** in my case I show them history of cancer research **(CE-SP: Processes of inquiry):** how a scientist developed the methodology **(SI- Social organizations and interactions):** I tell them about Noble prize winners in biomedical sciences, noble prize winners in genetics, in biochemistry, in cancer research too for them to appreciate the advancements.	

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			field but also of the scientific advancements and what are the important discoveries. I tell them about Noble prize winners in biomedical sciences, noble prize winners in genetics, in biochemistry, in cancer research too for them to appreciate the advancements so definitely history is very important. I even tell them that cancer is not a new disease even during Pharaoh time there are drawings that show patients with tumors growing from their body, it's not a new disease. So, I rely on history, on discoveries that happened 1000, 2000 years ago.		
	FAFS	FAFS-P2	Ya, of course. There are precise methods to follow in science	**(CE-SP: Processes of inquiry):** There are precise methods to follow in science	
		FAFS-P4	Yes, definitely. I think the scientific methodology is very important to help them to understand and to help them explain results because sometimes we see results by some people is different from results by others, maybe they use different methods you know, it's not really because is a contradiction of things but I think the way you approach things is really different	**(CE-SM: Reasoning strategies)** scientific methodology is very important to help them to understand and to help them explain results	**(CE-SM: Reasoning strategies):** we see results by some people is different from results by others, maybe they use different methods you know, it's not really because is a contradiction of things but I think the way you approach things is really different

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
Q5: Do you think that teaching students about scientific aims and values improves their scientific literacy?	FAS	FAS-P5	Sure definitely. Aims, aim is important because I think it gives them a better guidance in their scientific model otherwise it's going to be all of a place but at the same time the aim has to be flexible so that you allow them to build on outliers. Values is also important because I believe when we do science as well it's like, we are dealing with integrity with some sort of scientific integrity where I cannot infer things from data that do not exist because it feeds into my intuition so it's very important to learn the tool to define the uncertainty and the errors and all of this an know that this is the value of science. Even the output of it. The output has to serve at the beginning it's not necessary to serve; here we go back to the ethics of science that is whatever they come up with at the end should, how am I going to explain this. In my field, I don't have this problem; now we are talking about science that we come with it's not going to be unethical at one point of time. So, I am just thinking about development of drug; we have to know that whatever is developed out of it should have enough social awareness or good public sector that is capable of managing the output of science so that it doesn't become disruptive. This is important.	**(CE-SP: Model in the sense of an experiment):** a better guidance in their scientific model **(CE- AV: Empirical adequacy/ integrity):** when we do science as well it's like, we are dealing with integrity with some sort of scientific integrity. **(CE-SP: Experimentation/Tool):** it's very important to learn the tool to define the uncertainty and the errors and all of this **(SI-Social value):**The output has to serve at the beginning it's not necessary to serve **(SI-Scientific ethos):** the ethics of science	**(SI- Scientific ethos):** now we are talking about science that we come with it's not going to be unethical at one point of time. **(SI-Social value/ social awareness/ public sector):** I am just thinking about development of drug; we have to know that whatever is developed out of it should have enough social awareness or good public sector that is capable of managing the output of science so that it doesn't become disruptive.

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
		FAS-P7	Yes. In fact, in the last decade, we heard a lot about some papers that were withdrawn from journals because question mark about the data and integrity of researchers to publish these data so yes, I feel students they are aware about this so when they are doing for example, and this can happen especially when I ask them to reproduce the experiment OK, to do it once, twice, three times and to check. And sometimes they have garbage in, garbage out data so they question themselves, why am I not able to reproduce? You are not able to reproduce because something is wrong somewhere, right? so now, they are aware that data should be accurate, data should be reproducible, otherwise we cannot we cannot say that these data are publishable or serve the cause	**(SI- Scientific ethos/ integrity of researchers):** we heard a lot about some papers that were withdrawn from journals because question mark about the data and integrity of researchers to publish these data. **(CE-SP: Experimentation):** when I ask them to reproduce the experiment OK, to do it once, twice, three times and to check. **(CE-SP: Data collection):** they have garbage in, garbage out data **(CE- AV: empirical adequacy and reproducibility):** they are aware that data should be accurate, data should be reproducible, otherwise we cannot we cannot say that these data are publishable or serve the cause	
		FAS-P12	Yes, I mean aims and values I think ultimately its reading scientific literature, reading primary literature and not just one, you know multiple papers on the same topic is what gives a better sense. So, if you pick one narrow topic and then look at all the papers about that you realize how the results fluctuate and how they are contradictory and also how over time certain more solid results emerge. I think that and I have done that in seminars and I	**(CE-SP/ Reading and comparing literature):** reading scientific literature, reading primary literature and not just one, you know multiple papers on the same topic is what gives a better sense. **(CE-SM: Reasoning strategies):** look at all the papers about that you realize how the results fluctuate and how they are contradictory and also how over time certain more solid results emerge. **(SI- Professional activities):** I have done that in seminars.	

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			think for some students it was eye opening.		
		FAS-P13	Yes, yes. I think it will. Yes, I think they are. I don't know frankly now. Let me think about it. It's debatable because you do have sometimes excellent scientists who are not socially aware or lack in humane characteristics. So it is a long term process I will say, but it is something that needs to be done because on the long run yes.	**(SI-Scientific ethos):** you do have sometimes excellent scientists who are not socially aware or lack in humane characteristics.	

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
	FEA	FEA-P1	Do I think that teaching students about scientific aims and values helps them improve their scientific literacy? Definitely, I think YEAH, I mean they need to be aware of, again the very similar question in my opinion, the WHY questions why do we do this? Why do we? Why are we doing this experiment? Why are we looking for the next fastest most effective computer system or algorithms or way of treatment for a certain disease so you need to understand the aims because if you understand the aims you may help in finding better solutions. And then the values again we cannot lose sight of… again similar the why, why are we doing this what do we get out of it what is the real value of our work I am not just doing this work because my advisor or professor asked me to do it. I'm doing this work because this is what it does to humanity, this is what it does to my community, this is what it does to….	**(CE-SP: Posing questions):** the WHY questions why do we do this? Why do we? Why are we doing this experiment? **(SI-Social value):** Why are we looking for the next fastest most effective computer system or algorithms or way of treatment for a certain disease so you need to understand the aims because if you understand the aims you may help in finding better solutions.	**(CE-SP: Posing questions):** why, why are we doing this what do we get out of it **(SI- Social value):** I'm doing this work because this is what it does to humanity, this is what it does to my community.
	FEA	FEA-P8	Ya, sure for the same reasons I mentioned earlier.	**(CE-AV-evidence/ empirical adequacy):** for the same reasons I mentioned earlier (Evidence based)	

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
	FHS	FHS-P2	I think it does so how are you going to raise their motivation and make them interested in your topic if you don't explain what it is going to be used for. For example, whenever I start my courses, I have another course it's medical imaging pathologies. I try to give them personal examples from my life, from the cases that I have seen to engage them into the conversation and try to relate what they see in their own life to what they are studying. This way they will be more engaged, more motivated to study and to be interested in the topic that they are studying so it's not just about getting a degree and then work, for me working with your degree should be a passion. Work should be a passion. If it's not a passion for you don't do it. If you want to go for something, you hate you will be miserable all your life. So, I always recommend that they choose something they love, they have a passion for.	**(SI-Social value/ Uses):** How are you going to raise their motivation and make them interested in your topic if you don't explain what it is going to be used for. **(SI-Scientific ethos: Motivation for doing science):** This way they will be more engaged, more motivated to study and to be interested in the topic	**(SI- Social value):** I try to give them personal examples from my life, from the cases that I have seen to engage them into the conversation and try to relate what they see in their own life to what they are studying. **(SI- Scientific ethos: Motivation and passion for science):** it's not just about getting a degree and then work, for me working with your degree should be a passion. **(SI- Scientific ethos:Passion for doing science):** Work should be a passion. If it's not a passion for you don't do it. **(SI- Scientific ethos:Passion for doing science):** I always recommend that they choose something they love, they have a passion for.
	FM	FM-P3	Absolutely, it's a must. Ethics, ethics. In our PhD programs, we require ethics course but ethics is part of any teaching of any scientific inquiry. Ethics of science, ethics of being a good citizen. Absolutely, if you teach science and without ethics, that might lead to catastrophes so ethics should be incorporated in any course	**(SI- Scientific ethos):** Ethics, ethics. In our PhD programs, we require ethics course but ethics is part of any teaching of any scientific inquiry.	**(SI- Scientific ethos):** Absolutely, if you teach science and without ethics, that might lead to catastrophes so ethics should be incorporated in any course

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
		FM-P4	Of course. But the problem in our society is that we still consider teaching as filling information into the students' brains. For this in famous universities as MIT, they don't only consider your average. They choose students based on what the student can prioritize for instance if you took in some subjects higher marks than other subjects.	**(CE-SK: Information):** we still consider teaching as filling information into the students' brains.	
	FAFS	FAFS-P2	Yes definitely. If you learn something and you don't know its value and how to use it, you forget it and you will forget the value with it. And I teach them something more important than that: the ethics of that information and its application. I feel a lot of time. Do you want me to tell you last time what I did? I had a graduate student, 6 students: 5 Lebanese from 5 different religions, sects and 1African, a graduate course, open book, open computer, telephone everything. I told them, I was experimenting, I told them it's an open book test. All I want, I request don't talk to each other because there are things, everyone has to answer in a different way. If they talk to each other, I will get the same answer. Take two hours, you don't need more, take three hours, once you finish, bring the paper to my office. I am staying here with you for 15 minutes. Read the questions and you can ask if you	**(SI-Scientific ethos/ethics):** the ethics of that information and its application	**(SI-Scientific ethos/ ethics):** I had a graduate student, 6 students: 5 Lebanese from 5 different religions, sects and 1African, a graduate course, open book, open computer, telephone everything. I told them, I was experimenting, I told them it's an open book test. All I want, I request don't talk to each other because there are things, everyone has to answer in a different way. If they talk to each other, I will get the same answer. Take two hours, you don't need more, take three hours, once you finish, bring the paper to my office. I am staying here with you for 15 minutes. Read the questions and you can ask if you have any questions. They said OK, they will not talk to each other. I came her and left them. The 5 Lebanese spoke with each other. I was so disappointed. It hurts me up

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			have any questions. They said OK, they will not talk to each other. I came her and left them. The 5 Lebanese spoke with each other. I was so disappointed. It hurts me up till now. That African didn't. And then they came here. I asked them, they didn't lie they said YES. I asked them Why? And then I really was upset. I didn't fail them because sometimes I feel, anyway, its an open-book-test. But one thing I told them don't ever ask me to write your recommendation because If I do, I am going to say I'm sorry, a very good student, but he cheater that's the first sentence so don't ask me to write you recommendation. That's the only punishment I can give you. I feel if we don't teach, that's our problem, that's the problem of the human being, lack of ethics in applications. In applications of science, if any conductor is not ethical what would they do or anybody, a teacher, a lawyer, any, any, engineer just name it. So, ethics comes first. You can make a mistake but you cannot behave in an ethical way in any job in any application. At UC Davis, I was there and the system was there, honor system, the professor was not allowed to, it's humiliating to the students for someone to observe them if they don't cheat. Ok, I am giving you		till now. That African didn't. And then they came here. I asked them, they didn't lie they said YES. I asked them Why? And then I really was upset. I didn't fail them because sometimes I feel, anyway, its an open-book-test. But one thing I told them don't ever ask me to write your recommendation because If I do, I am going to say I'm sorry, a very good student, but he cheater that's the first sentence so don't ask me to write you recommendation. That's the only punishment I can give you. I feel if we don't teach, that's our problem, that's the problem of the human being, lack of ethics in applications. In applications of science, if any conductor is not ethical what would they do or anybody, a teacher, a lawyer, any, any, engineer just name it. So, ethics comes first. You can make a mistake but you cannot behave in an ethical way in any job in any application. **(SI- Scientific ethos/ ethics):** At UC Davis where I went, an honor system, you have a class and you have a question and you are not supposed to cheat and if you cheat and I saw you, I should report to. Who cheats? You

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			another example. At UC Davis where I went, an honor system, you have a class and you have a question and you are not supposed to cheat and if you cheat and I saw you, I should report to. Who cheats? You will have 50 students in the class let's say taking chemistry course. The Iranians and the Arabs. That's my experience, maybe others. When I was there, I avoided sitting next to any of them. I always tell my students please don't lie even if you don't know the answer to the question. So what? In your life, don't lie, you will always be happy and you will always be successful. Our problem in all leadership across the world is being professional liars, so ethics comes first. It takes generations to raise this ethics in a person. So, I feel the concentration on ethics, like in my old profession, I was in Saudi Arabia I developed a company I was the technical director of that company which produced fertilizers. You know if you are a farmer and you need 100 kg fertilizers, and I give you 200, they will give you the same yield. If I give you 300kg, it starts affecting the crop so they told the engineer, this man needs 10 bags, sell him 7 or 8 bags, in this way they sell more and they don't harm it. When I went into the company, I had 17 masters and BS, they		will have 50 students in the class let's say taking chemistry course. The Iranians and the Arabs. That's my experience, maybe others. When I was there, I avoided sitting next to any of them. I always tell my students please don't lie even if you don't know the answer to the question. So what? In your life, don't lie, you will always be happy and you will always be successful. Our problem in all leadership across the world is being professional liars, so ethics comes first. It takes generations to raise this ethics in a person. **(SI- Scientific ethos/ ethics):** I was in Saudi Arabia I developed a company I was the technical director of that company which produced fertilizers. You know if you are a farmer and you need 100 kg fertilizers, and I give you 200, they will give you the same yield. If I give you 300kg, it starts affecting the crop so they told the engineer, this man needs 10 bags, sell him 7 or 8 bags, in this way they sell more and they don't harm it. When I went into the company, I had 17 masters and BS, they are sale engineers, they go and they sell farmers. We collect soil samples and

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			are sale engineers, they go and they sell farmers. We collect soil samples and then we give recommendations. They used to collect soil sample, give the recommendation to the engineer to sell the farmers. When I started, I told them the samples come, the results come to me, I send the results directly to the customer. They say: how can you sell him? Maybe he goes and buy it from somewhere else, I told them No why should they buy it from somebody else? We already did the analysis for him for free, we have a product if it's good as others, if our prices are as good as others, he will buy it from us. If he doesn't and I give him the recommendation and I never give a recommendation higher than required, they said you tell us give 100 and the directors asks them to sell more. Instead of selling 200 for one person you go to two persons and sell 100 each. We tried it this way after two years, we no longer went to the customers, they came to us. We didn't have to look for customers. Ethics is the most important thing. Don't lie. So ethics.		then we give recommendations. They used to collect soil sample, give the recommendation to the engineer to sell the farmers. When I started, I told them the samples come, the results come to me, I send the results directly to the customer. They say: how can you sell him? Maybe he goes and buy it from somewhere else, I told them No why should they buy it from somebody else? We already did the analysis for him for free, we have a product if it's good as others, if our prices are as good as others, he will buy it from us. If he doesn't and I give him the recommendation and I never give a recommendation higher than required, they said you tell us give 100 and the directors asks them to sell more. Instead of selling 200 for one person you go to two persons and sell 100 each. We tried it this way after two years, we no longer went to the customers, they came to us. We didn't have to look for customers. Ethics is the most important thing. Don't lie. So ethics.

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
		FAFS-P4	Yes, definitely, Ya. Let me tell you why because you see sometimes students they really want to study in order to get grade or to get a job and they don't really have deep thinking about what's the objective of science so if you tell them about you know history of certain things, how it moved, how it changed, how curiosity I want to know what happened and then later on I tried this it didn't work so I searched for something else and then you end up with discoveries, I always give history about thing in my teaching like this was discovered by this person at this time and it took this time to discover the other step you know we observe this and then later on we try to find the causes of this so you need to trigger their curiosity about things you know to understand you know because I teach nutrition I tell them I am not going to tell you what does the food have I want you to know why this wasn't there and then you can understand, you can apply to any other setting in a way.	**(CE-SK: history of scientific knowledge):** what's the objective of science so if you tell them about you know history of certain things, how it moved, how it changed. **(CE-SP: Processes of inquiry):** I want to know what happened and then later on I tried this it didn't work so I searched for something else **(CE-SK: resultant knowledge):** and then you end up with discoveries **(CE-SP: Making observations):** you know we observe this **(CE-SP: Making predictions):** we try to find the causes of this **(CE-SP: Processes of inquiry):** what does the food have I want you to know why this wasn't there and then you can understand, you can apply to any other setting in a way.	**(CE-SK: history of scientific knowledge):** I always give history about thing in my teaching like this was discovered by this person at this time and it took this time to discover the other step
Have you ever attended any workshops about nature of science?	FAS	FAS-P5	***P8: How?*** ***I: How science develops, its epistemological groundings?*** No not really, and I have never thought about it. I use chemistry a lot and also physics and	**(CE-SK: knowledge):** Because geoscience had been always about knowledge since it is based on chemistry and physics **(CE-SP: tools):** Whereas you have to teach the tools and methods	**(CE-SP: tools)** I teach him a case-specific as an example of something around me and he has to derive the rest because he sees the same behavior in the rest of them or he knows how a governing process

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			math. In case of geology, I know how it developed and actually now we are in the process of changing If you look at how geosciences are approached everywhere else so there is an initiative to see where are we heading. Because geoscience had been always about knowledge since it is based on chemistry and physics but it reached a place where chemistry and physics was used by the ones who developed the concept and now, we convey the concepts to students without going back to the model itself that others used to develop these things which is very wrong in my opinion. Whereas you have to teach the tools and methods so that he and I teach him a case-specific as an example of something around me and he has to derive the rest because he sees the same behavior in the rest of them or he knows how a governing process applies under different conditions and this needs teaching the tools of science and not transfer of knowledge so you have to put effort in chemistry, math and physics so that he can be able to develop his/her own concepts. And this is even harder than just being limited to the physics, math and chemistry and this is what we should teach and I have read the new initiative about geoscience and all these and how things		applies under different conditions and this needs teaching the tools of science and not transfer of knowledge

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			are changing because it no longer fits but for other sciences I don't know , I didn't look at them because I consider them more quantitative nd they are not facing the same problems that unfortunately geology is facing. I think or they have picked up before I don't know I think biology is changing because they integrated in it genetics and bioinformatics because science has to follow up with technology and we shouldn't forget that it shouldn't become taking for-granted whatever others have done so there are challenges in the non-quantitative sciences where we should go into ways where students are very powerful in this science itself but at the same time they can use other tool to achieve better results.		
		FAS-P7	I don't think so. No about the nature of science No. You know because I am not really, so I am in the Chemistry Department, I am working on water treatment, water conservation, sometimes on forensic science also counter fitting. I am not, I got engaged into education when I worked on DIRASATI project so we developed lab manuals and we trained professors at schools. I was able also to organize workshops for professors also in schools how to manage a laboratory etc. At that	**(SI- Professional activities):** when I worked on DIRASATI project so we developed lab manuals and we trained professors at schools. **(SI-Social values):** this will give you more confidence that what you have done is really something that was very helpful for them and for the society where they are living.	**(SI- Professional activities):** I was able also to organize workshops for professors also in schools how to manage a laboratory. **(SI- Professional activities):** how to rely the message OK to the people, students to anyone

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			time, I got engaged into education and I like the sense not a pure, pure chemist, education is very, very important, you learn more when you do education, how to rely the message OK to the people, students to anyone and the feedback is very important so when you have the feedback from them through surveys, this will give you more confidence that what you have done is really something that was very helpful for them and for the society where they are living.		

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
		FAS-P12	I have read literature ya, ya I am interested in that. I read an article recently by Conman this, this I guess this economist/psychologist about what's this called adversarial collaboration where he talks about how the standard procedure in scientific journals are having comment where people can comment on other people's articles and then they rebuttal how this is essentially he feels like that this is pretty not this, counterproductive, adversarial it refers to name calling disguised in scientific terminology but this and its much better if you have somebody having an opposing view to collaborate with them. And the way he describes it is that with the person who has the opposing view whether you both come up with an experiment where you both agree on the outcome would judge who is right and who is wrong where you agree before Ok so if the experiment does this then and he says usually what happens is that both scientists agree then there is an outcome and the person who sorts of was proven wrong then also comes up with all sorts of ideas why this was not the right experiment. In the end it doesn't quite work but I find it a very loosest description of the program and I am interested in that because part of my	**(SI- Social certification and dissemination of scientific knowledge):** Adversarial collaboration where he talks about how the standard procedure in scientific journals are having comment where people can comment on other people's articles and then they rebuttal how this is essentially he feels like that this is pretty not this, counterproductive, adversarial it refers to name calling disguised in scientific terminology but this and its much better if you have somebody having an opposing view to collaborate with them. **(CE-SP: process):** this scientific method might break down **(CE-SK: core/ phenomena):** what the core of science is so for what kind of phenomena the scientific method might not be applicable anymore **(CE-SP: Posing questions):** what are some useful questions to ask.	**(SI- Social certification and dissemination of scientific knowledge):** And the way he describes it is that with the person who has the opposing view whether you both come up with an experiment where you both agree on the outcome would judge who is right and who is wrong where you agree before Ok so if the experiment does this then and he says usually what happens is that both scientists agree then there is an outcome and the person who sorts of was proven wrong then also comes up with all sorts of ideas why this was not the right experiment. In the end it doesn't quite work but I find it a very loosest description of the program and I am interested in that because part of my research is sort of at the edge of, I think what's scientifically knowable so I have a bit of ecology research. **(CE-SK):** some areas of Biology where they deal with the phenomena that is so complex that they might not be demandable to scientific investigation or whether scientific method might break down

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
			research is sort of at the edge of, I think what's scientifically knowable so I have a bit of ecology research. I feel like there is something where this scientific method might break down and there is another a famous talk by Richard Feynman the physicist where he compares science with Cargo Cult I think it was a commencement speech in the 70s that I find also very interesting because it tells ,you know, what the core of science is so for what kind of phenomena the scientific method might not be applicable anymore and he talks about psychology research too and I feel like some areas of Biology where they deal with the phenomena that is so complex that they might not be demandable to scientific investigation or whether scientific method might break down so I am that's why I am interested in you know to understand what are some useful questions to ask.		
	FEA	FEA-P1	No		
	FEA	FEA-P8	No		

Question Set 3	Faculty	Participant code	Answer	Analysis	Comments (Repitition / Emerging themes)
	FHS	FHS-P2	No. I haven't. I am kind of new to the university here so this is my third year. I am only starting now to attend some workshops for the Ctl.	**(SI-Professional activities):** I am only starting now to attend some workshops for the Ctl.	
	FM	FM -P3	No		
		FM -P4	Yes, of course.		
	FAFS	FAFS -P2	No		
		FAFS -P4	No		

Note. Color Coding: Blue for Cognitive Epistemic Themes, Red for Social Institutional Themes, Green for Repeated Themes, and Purple for Emerging Themes.

APPENDIX E
FREQUENCY COUNT OF CODED DATA

Question Set	Participant code	AV	SM	SP	SK	Professional activities	Scientific ethos	Social certification and dissemination of scientific knowledge	Social values	Social organizations and interactions	Political power structures	Financial systems
QS-1	FAS-P5	2	3	6	3	1	1	0	1	2	0	0
	FAS-P7	1	1	4	1	1	0	0	5	1	0	0
	FAS-P12	6	1	6	1	0	1	0	1	0	1	0
	FAS-P13	1	0	2	0	0	0	0	1	0	0	0
	FEA-P1	1	0	2	0	0	0	2	2	0	0	0
	FEA-P8	1	0	8	2	1	0	0	1	0	0	0
	FHS-P2	1	1	4	1	0	0	0	0	1	0	0
	FM-P3	1	1	3	0	0	1	0	3	0	0	0
	FM-P4	3	1	8	3	0	0	1	1	2	2	4
	FAFS-P2	1	1	7	1	0	0	0	1	0	0	0
	FAFS-P4	1	0	4	1	0	0	0	2	0	0	1
		19	**9**	**54**	**13**	**3**	**3**	**3**	**18**	**6**	**3**	**5**
QS-2	FAS-P5	4	5	10	5	0	1	0	2	1	2	2
	FAS-P7	1	1	7	2	0	0	0	0	0	0	0
	FAS-P12	4	0	9	1	0	0	2	0	0	1	0
	FAS-P13	2	0	3	1	0	1	0	0	0	1	0
	FEA-P1	0	1	0	0	0	0	0	0	0	0	0

Question Set	Participant code	AV	SM	SP	SK	Professional activities	Scientific ethos	Social certification and dissemination of scientific knowledge	Social values	Social organizations and interactions	Political power structures	Financial systems
	FEA-P8	3	1	3	2	0	2	0	2	0	0	0
	FHS-P2	1	1	2	2	0	0	0	0	0	0	0
	FM-P3	0	2	0	0	5	0	1	2	2	0	3
	FM-P4	7	1	3	3	0	2	0	0	0	0	0
	FAFS-P2	3	2	2	1	0	0	0	0	1	0	0
	FAFS-P4	5	3	1	1	0	1	0	0	0	0	0
		30	**17**	**40**	**18**	**5**	**7**	**3**	**6**	**4**	**4**	**5**
QS-3	FAS-P5	4	3	10	4	0	2	1	4	0	1	0
	FAS-P7	3	1	5	2	3	1	0	4	0	0	1
	FAS-P12	1	2	5	4	4	0	3	1	0	0	0
	FAS-P13	0	1	0	1	0	1	1	2	0	0	0
	FEA-P1	0	0	3	1	0	2	0	2	1	0	0
	FEA-P8	4	1	2	0	0	0	1	1	0	0	0
	FHS-P2	2	1	2	1	1	1	0	2	0	0	0
	FM-P3	0	1	4	2	1	1	0	0	4	1	0
	FM-P4	0	0	0	1	0	0	0	0	0	0	0
	FAFS-P2	0	2	3	3	0	1	0	3	0	0	2
	FAFS-P4	1	1	5	4	0	0	0	2	0	0	0
		15	**13**	**39**	**23**	**9**	**9**	**6**	**21**	**5**	**2**	**3**
Total Sum		**64**	**39**	**133**	**54**	**17**	**19**	**12**	**45**	**15**	**9**	**13**

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