Maltese Post-Secondary Lecturers' Views on the Nature of Science

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ABSTRACT

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The major aim of this study was to investigate the nature of science [NOS] views of Maltese, post-secondary lecturers. The SUSSI questionnaire was used as the main research tool coupled with semi-structured interviews that were based on the VNOS-Form C questionnaire. A total of 252 questionnaires were collected from lecturers in the church, state and independent sixth form colleges, the University of Malta and the Malta College of Arts, Science and Technology. Ten online interviews were carried out with lecturers teaching various subjects in different institutions. Maltese lecturers tended to have transitional to adequate views on five NOS components, namely the tentativeness of scientific theories, scientific methodology, the social and cultural aspect of science, the use of imagination and creativity in science and the nature of observations and inferences. In turn, inadequate views were observed regarding the distinction between laws and theories.

A high uniformity of views was found when looking at the NOS ideas of various subgroups. No differences were found by age group and lecturing experience while gender only yielded a statistically significant difference on the distinction between laws and theories. Comparison by area of specialisation showed that applied science lecturers tended to have more naïve views on most NOS components, yielding statistically significant differences on the use of imagination and creativity in science and the change of scientific theories. Views were also compared by closest traditional science area, where lecturers with Physics as closest science area exhibited more naïve views on both change of scientific theories and the social and cultural aspect of science. Finally, NOS views were compared by highest qualification, where lecturers with a PhD appeared to have significantly better views on change of scientific theories.

Supervisor **M.Ed.Science Education**

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NATURE OF SCIENCE **SCIENCE LECTURERS**

HUMANITIES LECTURERS **POST SECONDARY**

AUTHOR'S DECLERATION

Ideclare that this is the authentic work of the author and that no part of it has been published elsewhere. This work is being presented in part fulfillment for the Degree of Masters in Science Education.

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RACHEL PACE

DEDICATION

…to my mother

who instilled in me a love for learning.

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I would like to thank all those who supported me throughout the write-up of this dissertation.

Firstly, I would like to thank my supervisor Dr M. Musumeci for his guidance and encouragement throughout this work. It was thanks to his positive attitude and continuous support and feedback that I managed to finish this work.

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LIST OF ABBREVIATIONS

AAAS: American Association for Advancement in Science

DLAP: Directorate for Learning and Assessment Programmes

FOS: Features of Science

FRA: Family Resemblance Approach

FREC: Faculty Research Ethics Committee

GDPR: General Data Protection Regulation

ICT: Information and Communication Technology

NOS: Nature of Science

SI: Scientific Inquiry

MCAST: Malta College of Arts, Science and Technology

MEDE: Ministry for Education and Employment

MQF: Malta Qualifications Framework

NOSI: Nature of Science Instrument

NOSS: Nature of Science Scale

NSTA: National Science Teachers Association

SEVs: Scientific Epistemological Views

SUSSI: Student Understanding of Science and Scientific Inquiry

SVI: Schwartz Values Inventory

TLS: Teaching Learning Sequence

TOUS: Test on Understanding Science

UOM: University of Malta

VNOS: Views on the Nature of Science

VOSE: Views on Science and Education

VOSTS: Views on Science-Technology-Society

WISP: Wisconsin Inventory of Science Processes

1. Introduction

1.1. Origin of the Research question

I tend to be a very sceptical person. Perhaps it is this trait which led me to choose the sciences in the first place and eventually to continue my undergraduate and now Masters dissertation on the nature of science [NOS] as a discipline. However, this journey has been quite a bumpy ride due to the Covid-19 pandemic. Following the findings in my undergraduate dissertation and the recommendations by Vella Bondin (2016) I initially planned a study whereby aspects of the NOS were to be implemented and investigated in Year 7 classrooms. I wanted to see how effectively I, as an integrated science teacher, will manage to implement these aspects of the NOS within the current syllabus and time-frame. I also felt that through this I would be enriching the students' experience of science while targeting scientific literacy and critical thinking better.

Due to circumstances, my plans had to change completely as schools closed in March 2020 due to the Covid-19 pandemic. As Maltese schools shifted to an online system, I was unable to collect data using the methods initially proposed and I could not implement the NOS activities in my classrooms as initially planned. Given that we were not sure if schools were going to open the following scholastic year, I opted to change my proposal entirely.

When considering the uncertainty of the opening of schools, I decided to collect data from an adult population who will have easier access to online means. In my undergraduate dissertation, I found out that most undergraduate students tended to have transitional to inadequate views on the NOS and that there was only little difference between science and non-science students. Subsequently I decided to study the NOS views held by local post-secondary lecturers inthe various sixth forms, the University of Malta [UOM] and the Malta College of Arts, Science and Technology [MCAST] who ultimately teach these students.

Considering the study carried out by Vella Bondin (2016) I could also compare the views of these lecturers with those of science teachers. The new research questions ultimately enabled me to carry out the study within the parameters brought about by the pandemic.

1.2. Context of the Study

Education in Malta is compulsory for ages five to sixteen. Post-secondary education starts beyond the age of 16 and is non-compulsory. In Malta non-compulsory education includes further and higher education. The term 'further education' refers to non-compulsory learning that enables students to obtain a national qualification up to level 4 within the Malta Qualifications Framework [MQF] or a foreign qualification at a comparable level ("Education Act", 1991). The term 'higher education,' in turn, refers to non-compulsory education that enables students to obtain a national qualification at Level 5 or higher or an equivalent foreign qualification ("Education Act", 1991).

In Malta, there are various non-compulsory formal, non-formal and informal educational institutions that enable the attainment of such qualifications. For the purpose of this study, participants were lecturers teaching in non-compulsory, formal educational institutions. Non-formal and informal educational institutions were not considered. The non-compulsory, formal educational institutions included in this study are the various church, independent and state sixth forms, the UOM and the MCAST.

This study aimed to investigate the NOS views of lecturers teaching in science, science-related areas, religious studies, theology and philosophy in all these institutions.

1.3. Research area, questions and strategies

There is very little research targeting the NOS views of higher education teachers and/or lecturers both on an international (Irez, 2006) and a national level. The views of these lecturers, especially those preparing future scientists and science teachers, influence the NOS views of their students (Irez, 2006). Therefore, the aim of this study was to investigate the NOS views of

Maltese lecturers teaching various disciplines in non-compulsory, formal educational institutions in Malta. It aimed to investigate the views of lecturers teaching in science areas, in science-related areas, in theology, religious knowledge and philosophy. These views were then compared between various subgroups in the population. Thus, the following research questions were employed during this research study:

What are the NOS views of Maltese post-secondary lecturers?

- Is there a difference between pure science lecturers, applied science lecturers and humanities lecturers?
- Considering lecturers in the natural sciences and science-related courses, are there differences according to whether their background is biology, chemistry or physics?
- Is there a difference by years of experience in the field?
- Is there a difference by age bracket?
- Is there a difference depending on qualifications?
- Is there a difference between males and females?

A mixed-methods approach (Creswell, 2015) using a survey was utilised to target these research questions. The survey strategy enabled the collection of large amounts of data at a particular point in time, enabling wide and inclusive coverage (Denscombe, 2003). The self-completion questionnaire could easily be distributed online, overcoming the limitations brought about by the pandemic. The questionnaire included both close-ended and open-ended questions enabling participants to explain their views, giving the findings greater depth (Cohen et al., 2007). To enhance the depth and hence the construct validity of the findings, online interviews were also carried out (Cohen et al., 2007).

The findings from both the questionnaires and interviews were initially analysed separately and eventually merged to find out the NOS views of all participant lecturers. Further analysis then led to comparisons within the various subgroups. Such methodological triangulation (Greene et al., 1989) using a convergent design (Creswell, 2015) enabled the combination of two different sources of data that consider different viewpoints and perspectives, hence providing a richer picture of the findings (Johnston et al., 2007).

The final aim of this study was to ultimately provide, based on research findings, a better understanding of the NOS views of Maltese post-secondary lecturers. Subsequently a set of recommendations could be made to all stakeholders in the area, to ultimately target better the NOS and scientific literacy for students attending these institutions.

1.4. Structure of the dissertation

This dissertation is divided into four other chapters. The following is a brief description of each of these chapters.

The next chapter, chapter 2, is a literature review of contemporary studies in the area. Initially contemporary views and ideas on the definition of the term NOS are outlined, followed by why a proper understanding of the NOS is essential. Eventually the current views of various stakeholders in the area were described. This includes studies with younger students, undergraduates, pre-service teachers, in-service teachers, practicing scientists and lecturers. Both international and national studies were included. Eventually the various attempts used to alter NOS conceptions of various students and teachers were discussed. In the last part the range of assessment instruments developed to measure and study NOS views are described.

Chapter 3, is the methodology chapter that outlines the theoretical position and subsequent research approach adopted in this study. It gives a detailed description of the research strategy used and the research tools adopted, outlining both their advantages and limitations. It also describes in detail the context of the study, how participants were recruited and how the data was ultimately collected. Eventually, it discusses the steps taken and decisions made to increase the reliability and validity of the findings. In the last part it discusses how the data from both the questionnaire and the interview was analysed and eventually merged to provide a comprehensive and empirical description of the findings.

Chapter 4 is the results and discussion chapter that provides a detailed description of the findings of this study. Initially a description of the overall views of all participant lecturers was given, merging data from the closed questions, the open questions and the interviews. Following this, the views of participants within various subgroups were compared. These subgroups included gender, age group, lecturing experience, area of specialisation, closest traditional science area and highest qualification respectively. Tables, graphical representations,various statistical tests and excerpts were used to present and analyse this data. Findings were eventually discussed and compared to other findings both on anational and international level.

Chapter 5 is the final, concluding chapter of this study. It provides a summary and discussion of the major findings of this study followed by a discussion of implications based on these findings. Eventually it outlines the major strengths and limitations of the study. Finally, it makes a set of recommendations for future research in the area.

2. Literature Review

Despite various pedagogical emphases, most countries advocate a proper understanding of the nature of science [NOS] and scientific inquiry [SI] (American Association of Advancement in Science [AAAS], 2009; Deng et al., 2011; Lederman and Lederman, 2014; Neumann and Vesterinen, 2017; Vesterinen and Izquierdo, 2015). However, before attempting to teach such a construct, one should try to define it, become aware of contemporary research in the area, and discover the views held by teachers and students and attempts made to teach and deliver the construct.

2.1. Defining the Nature of Science (NOS)

Lederman (2007) argues that "[o]ne of the most vexing issues for those who do research on the teaching and learning of the nature of science (NOS) is that NOS can be a moving target." (Lederman, 2007, p. 835). Infact when considering the main narratives in the area such as Popper (1959), Kuhn (1962), Lakatos (1978) and Feyerabend (1975), one realizes that the notion of the NOS is as dynamic as scientific knowledge itself.

There are two main views of what defines the NOS, namely the 'general aspects view' (Kampourakis, 2016) also known as the 'consensus view' (Noronha and Gurgel, 2013, 2015, 2017; Vazquez-Alonso and Manassero-Mas, 2017) and the alternatives or criticisms of such a view, usually termed the 'non-consensus view'.

The 'general aspects view' of the NOS was popularized mainly by Lederman (2007). Various authors agreed that when considering views about the NOS by specialists in the area, such as scientists, philosophers of science and science educators, there is no general consensus on what constitutes the NOS (Lederman, 2007; Collins et al., 2003;McComas, 2008).Notwithstanding, they claimed that such discrepancies should not be problematic at the secondary school level.Subsequently, a number of studies empirically identified severalaspects of the NOS that are suitable for this level.

For example, Lederman (2007) identified six aspects of the NOS.These are: 1) the distinction between observations and inferences where observations are descriptive statements of natural phenomena that are directly accessible to the senses while inferences are interpretations of those observations; 2) the distinction between scientific laws and theories whereby laws are statements or descriptions of the relationships among observable phenomena while theories are inferred explanations for observable phenomena; 3) scientists use both creativity and imagination throughout the process of developing new scientific knowledge; 4) scientific knowledge is subjective and/or theory-laden as scientists' previous knowledge and experiences influence their work; 5) science is influenced by society and culture while it influences society and culture itself; and 6) scientific knowledge is tentative and subject to change.

Collins et al. (2003) carried out a study with twenty-five experts in different fields including science education, science, history, philosophy and sociology of science, science teaching and activities to promote the public understanding of science. Following the study, they identified nine aspects of the NOS. Four of these - namelyanalysis and interpretation of data; creativity; science and certainty; and cooperation and collaboration in the development of scientific knowledge- overlap with the aspects proposed by Lederman (2007). However, another five aspects of the NOS were also identified. These include a) scientific method and critical testing which emphasizes the use of the experimental method and basic techniques like controls and replicability; b) historical development of scientific knowledge; c) science and questioning, that is the continual and cyclical process scientists use when they ask questions and seek answers that would lead them to new questions; d) diversity of scientific thinking where one recognizes that science uses a range of methods and approaches; and e) the use of hypotheses and predictions in the development of new scientific knowledge.

In another similar study,McComas and Olson (2002) qualitatively analysed several international science education standard documents to identify what elements best represent the NOS. The authors argued that aspects of NOS in these documents overlap considerably and draw upon four disciplines, namely philosophy, history of science, sociology and psychology. In a successive study McComas (2008) then identifies nine core NOS ideas suitable for the science classroom.

Six of these aspects of the NOS overlap with those described by Lederman (2007) and Collins et al. (2003). These include a) aspects of scientific method and the different methods used to acquire new scientific knowledge; b) scientific knowledge as tentative, durable and self-correcting; c) the distinction between scientific laws, scientific theories and hypotheses; d) the use of creativity in science; e) the subjective and theory-laden NOS and f) the historical, cultural and social influences on the practice and direction of science. Three other aspects which were not mentioned include the limitations of science in answering all kinds of questions; how science and technology impact each other but are not the same; and how science produces demands but also relies on empirical evidence.

Considering the aforementioned studies in the area, one cannot say that different authors actually agree on all aspects of the NOS, yet there is considerable overlap and, consequently, together these constitute the 'general aspects view'. From these studies the most widely used aspects of the NOS are those proposed by Lederman (2007) (Kampourakis, 2016; Matthews, 2011). Thereafter, a number of studies proposed ways to teach these NOS aspects to students at different levels and to pre-service and in-service teachers. Other studies focused on developing assessment instruments to measure NOS views, with the most popular being the Views on the Nature of Science [VNOS] (Lederman et al., 2002) and the Views on Science-Technology-Society[VOSTS] questionnaires (Aikenhead and Ryan, 1992).

Notwithstanding, the 'general aspects view' still received ample criticism from authors who favour a broader definition of the NOS (Grandy and Duschl, 2007; Irzik and Nola, 2011; Kampourakis, 2016; Matthews, 2011; Noronha et al., 2013, 2015, 2017; Vazquez-Alonso and Mannasero-Maz, 2017). For example Irzik and Nola (2011) criticize this view for a number of reasons, namely that-

1) it gives a narrow perspective of science ignoring aspects of scientific methodology;

2) it considers scientific inquiry (SI) as a separate construct from the NOS when in reality one cannot separate the methods used to generate scientific knowledge, that is SI, from the

epistemological standpoint and social context in which the knowledge is developing, hence the NOS;

3) it ignores variations in different scientific disciplines; and

4) the tenets presented in the 'general aspects view' seem to lack unity, that is there seems to be tension between some of the aspects.

Subsequently, these authors propose the 'family resemblance approach' [FRA] as a better approach to define the NOS. Based on Wittingstein's philosophy, this approach views the various science disciplines as members of a family (Irzik and Nola, 2011; Kampourakis, 2016). The authors claim that this is a better view as it is more comprehensive, and while it unites all the sciences, it is also sensitive to their differences, thus capturing"the dynamic and open-ended nature of science" (Irzik and Nola, 2011, p. 602).

Matthews (2011) in turn is also highly critical of the 'general aspects views' and brings about a number of philosophical and ontological arguments against it. While recognizing the efforts of Lederman and colleagues in effectively implementing aspects of the NOS in science classrooms he argues that,

> [t]he negative side is that the list can, despite the wishes of its creators, function as a mantra, as a catechism, as yet another something to be learned…it is directly antithetical to the very goals of thoughtfulness and critical thinking that most consider the reason for having NOS (or HPS) in the curriculum. (Matthews, 2011, p. 8).

In fact, the author goes on to criticize nearly every aspect of Lederman's list and ultimately proposes a change in the denomination from NOS to features of science [FOS] while enlisting another eleven aspects of FOS. These include: Experimentation; Worldviews and Religion; Idealization; Theory Choice and Rationality; Values and Socio-scientific issues;Models; Feminism; Explanation; Mathematisation;Technology;Realism and Constructivism. Matthews (2011) proposes that these FOS aspects also incorporate "epistemological, historical, psychological, social, technological, economic" (p. 13) aspects of the NOS that characterize the scientific endeavor and can therefore also feature in science classrooms.

From a more ontological standpoint Noronha et al. (2013, 2015, 2017) tend to agree with Matthews (2011) as they strongly criticize Lederman's empirical rendering of aspects of the NOS highlighting the fact that a realism-anti-realism philosophical debate is still unresolved in various disciplines, including science education, to this day. Consequently, they argue in favour of a 'non-consensus view' that promotes philosophical pluralism, encapsulating even controversial aspects of science. Matthews (1994) (as cited in Noronha et al., 2013) claims that a common occurrence of this in science classrooms is:

> …a child asking: If no one has seen atoms, how come we are drawing pictures of them? Such a child is raising one of the most interesting questions in philosophy of science: the relationship of evidence to models, and of models to reality. Good science teachers should encourage such questions and be able to provide satisfactory answers, or suggestions for further questions. (Matthews, 1994, as cited in Noronha et al., 2013, p. 1018)

Subsequently, Noronha et al. (2013, 2015, 2017) promoted a philosophical pluralism that opposes both 'Wittingstein's silence' and Feyerabend's 'anything goes.'Feyerabend's 'anything goes' favours a methodological anarchy in science, whereby scientific knowledge can be produced using different methods (Feyerabend, 1975). 'Wittingstein's silence' in turn refers to his 7th principle in his book 'Tractatus Logico-Philosophicus' which says,"[w]hereof one cannot speak, thereof one must be silent" (Wittingstein, 1922, p. 110). Following his previous six principles about the use of language, Wittingstein said that non-factual concepts such as those in religion, aesthetics and ethics are essentially unsayable and meaningless, so one should not discuss them. Thus, Wittingstein and Feyerabend propose only a single perspective within philosophy of science. While Noronha et al. (2013) recognise such perspectives, they argue in favour of a 'democratic solution' that promotes discussion on such non-consensual aspects of the NOS in the classroom. This, they argue, will provide a“promising way to make NOS relevant both epistemologically and politically to science education” (Noronha et al., 2017, p. 855).

Despite such harsh disputes, Lederman’s ‘general aspects view’ is still upheld by some authors (Kampourakis, 2016). For example while recognizing given criticisms, Kampourakis (2016) put forward the following arguments in favour of the ‘general aspects view’ of the NOS:

> (1) Whatever is taught at schools has previously undergone some kind of didactic transposition (not just simplification) in order to align with the pedagogical goals.
> (2) The main aim of the “general NOS aspects” conceptualization is to address students’ preconceptions about NOS by discussing some aspects common across all science, not to give them criteria for demarcating science from non-science.
> (3) It seems unclear how(2) can be achieved if NOS instruction begins from the specifics ofthe various science disciplines and their differences, instead of general aspects that canthen be elaborated upon with reference to specific disciplines.
> (4) It seems pedagogically useful to distinguish between aspects of NOS and aspects of SI because students have been found to conceptualise them independently.
> (Kampourakis, 2016, p. 676)

Notwithstanding, the author argues that while students should initially be familiarized with the general NOS aspects proposed by Lederman, it would make sense to eventually complement this by introducing the FRA approach to differentiate between the various science disciplines.

Considering the aforementioned arguments, it was ultimately decided that the ‘general aspects view’ will be adoptedsince the research instruments used for this research study implemented thisdefinition. Moreover, for the purpose of this researchstudy, SI willalso be regarded as a NOS aspect, as the authors of the ‘Student Understanding of Science and Scientific Inquiry’ [SUSSI] questionnaire,which is the instrument being used in this research study,considered it as such. The ‘Views on the Nature of Science’ [VNOS] – Form C instrument,on which the interview questions were developed,also considered SI as an aspect of the NOS. Below is a description of the six aspects of the NOS tested in the SUSSI questionnaire and the corresponding informed view on each aspect.

- Observations and Inferences: Science is based on both observations and inferences. Observations are descriptive statements about natural phenomena that are directly accessible to human senses (or extensions of those senses) and about which observers can reach consensus with relative ease. Inferences are interpretations of those observations. Perspectives of current science and the scientist guide both observations and inferences. Multiple perspectives contribute to valid multiple interpretations of observations.
- Tentativeness: Scientific knowledge is both tentative and durable. Having confidence in scientific knowledge is reasonable while realising that such knowledge may be abandoned or modified in light of new evidence or reconceptualization of prior evidence and knowledge. The history of science reveals both evolutionary and revolutionary changes.
- Scientific theories and scientific laws: Both scientific laws and theories are subject to change. Scientific laws describe generalized relationships, observed or perceived, of natural phenomena under certain conditions. Scientific theories are well-substantiated

explanations of some aspect of the natural world. Theories do not become laws even with additional evidence; they explain laws. However, not all scientific laws have accompanying explanatory theories.

- Social and Cultural embeddedness: Scientific knowledge aims to be general and universal. As a human endeavour, science is influenced by the society and culture in which it is practised. Cultural values and expectations determine what and how science is conducted, interpreted, and accepted.
- Creativity and Imagination: Science is a blend of logic and imagination. Scientific concepts do not emerge automatically from data or from any amount of analysis alone. Inventing hypotheses or theories to imagine how the world works and then figuring out how they can be put to the test of reality is as creative as writing poetry, composing music, or designing skyscrapers. Scientists use their imagination and creativity throughout their scientific investigations.
- Scientific Methods:Scientists conduct investigations for a wide variety of reasons. Different kinds of questions suggest different kinds of scientific investigations. Different scientific domains employ different methods, core theories, and standards to advance scientific knowledge and understanding. There is no single universal step-by-step scientific method that all scientists follow. Scientists investigate research questions with prior knowledge, perseverance, and creativity. Scientific knowledge is gained in a variety of ways including observation, analysis, speculation, library investigation and experimentation. (Liang et al., 2008, p. 19-20)

2.2. The importance of teaching the Nature of Science (NOS)

An adequate understanding of the NOS can be considered as an important aim of science education (AAAS, 2009; Deng et al., 2011; Lederman, 2007; Lederman et al., 2014; National Science Teachers Association [NSTA], 2000; Neumann et al., 2017; Vesterinen et al., 2015)since a proper understanding of the NOS is related to better scientific literacy (AAAS, 2009; Ledermanet al., 2014; NSTA, 2000). In fact, Clough and Kruse (2005) argue that misunderstandings of the NOS may be the cause of a number of unfortunate consequences. These may be poor social decision-making by both citizens and policymakers, gifted students (especiallywomen) opting out of science careers and difficulty in understanding science concepts.

Current national reform documents propose “scientific literacy for all learners” and “skills and ways of thinking that are important for decision-making” (Ministry for Education and Employment [MEDE], 2011, p. 25) as two main purposes of local science education. Additionally the recent Year 7 and Year 8 Learning Outcomes Frameworks (Directorate for Learning and Assessment Programmes [DLAP], 2018; 2019) both include collaborative learning as an aspect of the NOS while the Year 7 framework also mentions“the process of forming a theory” (DLAP, 2018, p. 14). Thus one can argue that, although not specifically mentioned in national reform documents, an understanding of the NOS is being inferred (Pace, 2014; Vella Bondin, 2016).

A proper understanding of the NOS has also been linked to good decision-making skills (Khishfe, 2012) especially when it comes to socio-scientific issues (Khishfe 2012). Moreover, it is also known to improve science learning in particular topics such as energy (Michel and Neumann, 2017), electricity and magnetism (Peters and Kitsantas, 2010) and socio-scientific issues (Flammer, 2006) like evolution (Gregory, 2008; Kim and Nehm, 2011). A proper NOS understanding is also known to promote the acceptance of evolution (Kim et al., 2011; Lambrozo et al., 2008; Tattersall, 2008) hence aiding the co-existence of scientific and religious beliefs as one realises that despite differences in the epistemologies of science and religion, both have similar values (Zimmerman, 2019).

Driver et al. (1996) summarise all the above as they identify five main reasons why a proper understanding of the NOS is essential. These include: a) utilitarian-it is useful in managing scientific and technological processes; b) democratic-it helps in decision-making especially on socio-scientific issues; c) cultural-it helpscitizens appreciate science as an element of our culture; d) moral-it helps in understanding the values that govern the scientific community and to realise that this includes moral commitment;and e) science learning-it enhances the learning of science.

Thus, one can argue that it is reasonable to place such emphasis on the teaching of the NOS (Lederman, 2007; Lederman et al.,2014) as unless a critical number of individuals reach a proper understanding,one cannot assert that the above goals of science education are being reached.

2.3. Views on the NOS

As Lederman et al. (2014) put it when taking into account "the longevity of objectives related to students' conceptions of NOS, it is more than intriguing that research on NOS only began in earnest in 1961." (Lederman et al., 2014, para. 12). The first study was carried out by Klopfer and Cooley using the Test on Understanding Science [TOUS]. This study showed that high school students' understandings of the NOS and of scientists were inadequate (Klopfer and Cooley, 1963 as cited in Lederman et al., 2014). Since then, a considerable number of studies using a variety of assessment instruments were carried out with students of varying ages. Most studies were carried out with older, undergraduate students or pre-service teachers while a smaller number of studies were carried out with elementary, middle and secondary school students (Alan and Erdogan, 2018; Lederman, 2007).

2.3.1. Studies with elementary, middle and secondary school students

This section presents a number of studies in various countries on students' NOS views. One such local study is by Mifsud (1997) who studied the views of Form 3, Junior Lyceum students and their respective Physics teachers. The majority of students (84%) and their teachers were found to have decontextualized views of science as they believed that science is not influenced by society and culture. Students' views also appeared to be influenced by teachers' views. In a more recent study Das et al. (2019), who utilized the SUSSI questionnaire to investigate NOS views, also found that middle and high school students in Bhutan held inadequate views on the NOS. Students held naïve ideas on the social and cultural aspect of NOS, scientific laws and theories and science as a body of knowledge (Das et al., 2019).

Similarly, Kang et al. (2004) studied the views of 1,702 Korean 6^{th}, 8^{th} and 10^{th} graders using a multiple-choice questionnaire and open-ended questions. Students exhibited inadequate NOS views on the nature of scientific theories and their tentativeness irrelevant of their grade level. This indicated that a higher level of science education in Korea did not influence NOS views. Such findings are similar to those of other studies carried out in other countries. Chan and Tanner (2006) studied the views of 96, 7^{th} grade students in San Francisco. They reported inadequate NOS views as students tended to consider religion and science as distinct spheres while they also thought that imagination and creativity are not used in science. The study also showed that these beliefs are enforced early in the child's development (Chan and Tanner, 2006). Kucuk and Cepni (2015) used questionnaires and in-depth interviews to investigate the NOS views of 17, 7^{th} grade Turkish students. The majority of students (78%) had weak or varying views on the NOS while only 22% of students exhibited adequate NOS views.

In another Turkish study, Hacieminoglu et al. (2015) investigated the views of 3,062 students in 6^{th}, 7^{th} and 8^{th} grade. The 'Nature of Science Instrument' [NOSI] instrument was used as the tool to investigate four dimensions of the NOS, namely: tentativeness of science, the empirical NOS, the distinction between observations and inferences and the use of imagination and creativity in science. Most adequate NOS views were obtained on the empirical NOS, followed by the tentative nature of NOS. However,less adequate views were observed on the use of imagination and creativity in science and observations and inferences. More interestingly,this study attempted to reveal factors that influence students' NOS views. Results indicated that the physical infrastructure in school, educational resources available, parental educational level, self-efficacy, student achievement, experience of meaningful learning and learning goal orientation all positively impact NOS views. In a similar study, Abd-El-Khalick and BouJaoude (2003) investigated the NOS views of 80,7th and 8th graders that were randomly selected from four schools in Lebanon. While most students exhibited inadequate NOS views, the authors argued that NOS ideas tended to be influenced by students' socio-economic status and the type of school they attended to (Abd-El-Khalick and BouJaoude, 2003).

Several studies also compared the NOS views of students from different countries. For example, Griffiths and Barman (1995) compared the views of Canadian, American and Australian students using interviews. The sample consisted of 32 high school students from each country. A number of similarities and differences emerged. Students had similar ideas on certainty in science, the tentativeness of scientific theories and the hierarchical relationship between laws and theories. However, ideas on a single universal scientific method and the infallible nature of scientific laws were more evident in American students. Only a third of Canadian students mentioned the use of a traditional scientific method while the idea was completely absent in Australian students (Griffiths and Barman, 1995).

In a similar study,Park et al. (2013) studied the views of 521, 8th grade Canadian and Korean students using a survey with both quantitative and qualitative parts. The majority of students exhibited mixed views on the NOS: while they believed that scientific theories change, they also thought that empirical evidence is objective.The open responses of the survey also showed that culture and curriculum content tend to influence NOS views. (Park et al., 2013). Dogan and Abd-El-Khalick (2008) also found similar cultural differences in Turkish students. In fact, this study reports differences in students' views between Western and Eastern Turkey. NOS views of students were also influenced by other factors such as socio-economic status and parent education. When considering such findings, one tends to agree with Lederman et al. (2014) that students' "understandings of NOS are influenced by culture" (Lederman et al., 2014, para. 17).

Moreover, most elementary, middle and secondary school students appear to have inadequate or mixed views about the NOS. As Lederman et al. (2014) put it, "[w]ithout any targeted instructional interventions, students do not possess the currently desired understandings of NOS"(Lederman et al., 2014, para.19).This induced researchers to turn their attention to in-service and pre-service teachers' views of the NOS. The following section discusses these studies.

2.3.2. Views of undergraduate students, in-service and pre-service teachers

Foreign Studies

A teacher must possess clear conceptions of what s/he is attempting to teach to his/her students. This logic, coupled with the results presented above, caused researchers to turn their attention to teachers' and pre-service teachers' views of the NOS (Lederman et al., 2014). In fact, a much larger number of studies was carried out with undergraduate students, pre-service and in-service teachers (Alan et al., 2018; Lederman, 2007).

Research on teachers' views of the NOS dates to a study by Anderson (1950) where 56 Minnesota high school teachers were asked to answer eight questions on the scientific method (Lederman, 2007).The study revealed that they held misconceptions about the NOS. Later Carey and Stauss (1968), as cited in Lederman et al. (2014), investigated the NOS views of 17 prospective secondary science teachers using the Wisconsin Inventory of Science processes [WISP] instrument. Test scores indicated that these pre-service teachers held inadequate NOS views. Subsequently, an attempt was made to improve the teachers' conceptions through a science methods course and it was found that their views improved significantly.

In a later study Carey and Stauss (1970) used the WISP instrument to assess experienced teachers' conceptions of NOS. Results corroborated with those of the previous study showing that experienced teachers held naïve NOS views and that a science methods course improved WISP scores. Moreover,it resulted that years of teaching experience and grades did not affect NOS views.

Palmsquit and Finely (1997) in turn utilised an investigator-developed survey to study the views of NOS held by 15 students in a post-baccalaureate secondary science teaching course. Students held mixed views as they held contemporary views on scientific theories and the role of a scientist and a more traditional approach to scientific method. Haidar (1999) developed a questionnaire to assess the views of 31 pre-service teachers and 221 in-service chemistry teachers. The questionnaire was developed on the basis of five aspects of the NOS as identified by Palmsquit and Finely (1997), namely: scientific theories and models, role of a scientist, scientific knowledge, scientific method and scientific laws. Views were also found to be transitional as they varied from traditional to constructivist.

In another study with secondary science teachers, Aslan and Tasar (2013) used the Views on Science-Technology-Society [VOSTS] questionnaire to assess the NOS views of 74 Turkish science teachers. Participants held naïve views on many NOS dimensions. Additionally, NOS views did not influence their classroom practice.

Studies about NOS viewsare not limited to secondary science teachers. Bloom (1989),as cited in Lederman et al. (2014),carried out a study to describe pre-service elementary teachers' understanding of science. A sample of 80 pre-service elementary teachers, 86% of which were female,participated in the study. A questionnaire and a 21-item rating scale were used. A qualitative analysis of questionnaire responses showed that participants believed that the primary purpose of science is to benefit mankind. They also confused the meaning and role of scientific theories and this influenced the way they handle the topic of evolution in the classroom (Bloom, 1989 as cited in Lederman et al., 2014).

In another study, pre-service K-3 teachers' NOS views were investigated following a science methods course. The study aimed to investigate what relationships exist between the teachers' personal values, perceptions of values held by scientists and their NOS views pre- and post-instruction. Initially the Schwartz Values Inventory [SVI] was used to measure pre-service teachers' personal and cultural values and those they perceived to be the values of scientists. The Views of the Nature of Science [VNOS] - Form B questionnaire and interview werethen used to assess NOS views. Qualitative data such as teachers' course assignments were also used to substantiate findings. Before following the science methods course, K-3 teachers had values that were different from what they perceived would be the values of scientists. For example, they perceived scientists to be more powerful and high-achieving than themselves while they were also less traditional and conformative. Additionally,pre-test NOS views appeared to be naïve on NOS dimensions such as the distinction between laws and theories and observations and inferences. However, post-test scores showed improvement in NOS views and a better alignment of teachers' and scientists' perceived values. The authors argued that this similarity in values improved teachers' NOS conceptions as they became more willing and confident to teach science in their classrooms (Akerson et al., 2012).

Liang et al. (2009) in turn compared the NOS views of pre-service teachers from different countries. This large-scale international study had a sample of 640 pre-service teachers from three different countries namely the United States, China and Turkey. The SUSSI questionnaire,which is based on six different NOS aspects,was used to collect data. As in other studies (Pace, 2014) the pre-service teachers scored best on change of scientific theories and worst on scientific theories and laws. The Chinese sample scored best in five out of six aspects of the SUSSI, the American sample showed informed views on observations and inferences while the Turkish teachers scored lowest in all six aspects of the NOS. Miller et al. (2010) also used the SUSSI instrument to study the NOS views of undergraduate students. Both science and non-science majors "held a mix of naïve, transitional and moderately informed views"(Miller et al., 2010, p. 45) of the NOS. Once again naïve views were mostly held in the distinction between scientific laws and theories.

Local studies

Locally there has been three studies in the area. Cauchi (1999) studied the views of 102 pre-service primary teachers on various philosophical aspects of the NOS. Results were analysed based on gender, level of science education and subject group, that is whether their main area was a science or a non-science subject. Females appeared to have a more relativist and hence a better view of the NOS than their male counterparts. Language students in turn were more inclined towards a realist and deductivist perspective as opposed to science students. However, science students were more inclined towards instrumentalism, contextualism, inductivism, and positivism. Thus, a higher level of science education appeared to have affected NOS views both positively and negatively. However, considering the general, overall analysis, NOS views of Maltese undergraduate primary teachers tended to be inadequate.

Pace (2014) assessed Maltese undergraduate students' views on the NOS using the SUSSI questionnaire. It was found that undergraduate students have inadequate to transitional views of the NOS. Transitional views were exhibited on the tentative and subjective NOS and less adequate views were found in the social and cultural, imaginative and creative and scientific methodology. As in other studies (Liang et al., 2009; Miller et al., 2010) inadequate views were held on the distinction between laws and theories (Pace, 2014).

Vella Bondin (2016) carried out a local study with 219 science teachers from state, independent and church schools using the SUSSI questionnaire. Findings showed that more than half of participant teachers held adequate NOS views. However, despite this, Vella Bondin (2016) argues that teachers' informed NOS ideas do not influence their classroom practice. Generally, this is due to a content-laden syllabus which causes teachers to place more emphasis on subject content, due to classroom management issues and lack of teacher training.

Thus, when considering such studies one can argue that in general undergraduate students, pre-service and in-service teachers do not generally possess adequate NOS understandings (Lederman, 2007; Lederman et al., 2014), irrelevant of the grade level they teach,and the assessment instrument used. Moreover, years of experience and grades attained do not seem to influence NOS views (Carey et al., 1970 as cited in Lederman et al., 2014). In the next section the views of different professionals with various areas of specialisation are compared.

2.3.3. Views of different professionals

A number of foreign studies aimed to compare the views of various professionals including lecturers, teachers, scientists in different fields and philosophers of science. Such studies date back to Behnke (1961) who assessed the NOS understanding of 300 scientists, 400 biology teachers and 600 physical science teachers. According to Behnke (1961), as cited in Lederman (2007), "[o]ver 50 percent of science teachers felt that scientific findings were not tentative. Even more surprising was that 20 percent of scientists felt the same way." (Lederman, 2007, p. 839).

Kimball (1968) in turn used the Nature of Science Scale [NOSS] to compare the understanding of the NOS of 712 science teachers and scientists. Naïve views were held in both groups with no major differences between science teachers and practicing scientists. However, philosophy majors showed better NOS understanding than science majors and practicing scientists particularly in the methodology of science.

Wong and Hodson (2008) studied the NOS views of thirteen well-established scientists who identified a number of NOS aspects that are not evident in science curricula and textbooks. These include ideas on the methods used in science, science and technology and the role and status of scientific knowledge. In a later paper Wong and Hodson (2010) continue to discuss the social dimensions of science as viewed by scientists themselves. Both papers indicate that NOS is not simply a list of tenets that can be easily classified as "adequate" or not, based on a generalised statement. As the authors put it, "the "naïve" view that "science is universal" (held by all our scientists) coexists with the supposedly "adequate" view that science is socially and culturally embedded." (Wong and Hodson, 2008, p. 124). Overall this research study indicates that scientists tend to have different views than those held by science educators. Bayir et al. (2014) investigated the views of 69 scientists representing five scientific disciplines that included both natural and social scientists. Contrary to the above findings, participants held a mix of naïve to informed views, where views of natural and social scientists tended to be similar (Bayir et al., 2014).

Relatively few studies addressed the views of higher education teachers such as post-secondary teachers or science teacher educators (Irez, 2006). A study carried out by BouJaoude (1996) investigated the views of Lebanese educators and students including university professors who are post-secondary educators. Most university professors, teachers and students in this study held a traditional and hence naïve view on most NOS aspects resulting in students with a strong science content background that lacks "in knowledge about the nature of science, the role it plays in history, and the interrelationships among science, society and technology." (BouJaoude, 1996, p. 18).

In a more recent study Irez (2006)investigated the views of 15 prospective science teacher educators. Analysis of data revealed that most participants had inadequate views especially on the tentative NOS and scientific method. When comparing the background of these prospective science teacher educators it was found that those with an engineering background tended to have more absolutist and naïve views when compared to those with a science or education background. This was attributed to the fact that engineering courses tend to "require students to rely on precise measurements for successful applications and the use of analytic and structured method to obtain necessary data." (Irez, 2006, p. 1138). Another study targeted the views of graduate students who teach STEM courses to undergraduates and therefore are post-secondary lecturers (Wheeler et al., 2019). The study was aimed to use NOS instruction to alter NOS views of these graduate students. Pre-test scores however showed that alternative or naïve views were prevalent among participants especially on scientific methodology and the relationship between laws and theories (Wheeler et al., 2019).

Considering this, no local study has addressed or compared the NOS views of post-secondary education teachers or other local professionals such as scientists.In this study the term 'post-secondary' shall be referring to non-compulsory, formal education and shall therefore include both further and higher educational institutions ("Education Act", 1991). As described above the most similar local studywas the one carried out by Vella Bondin (2016) that targeted the views of science teachers who teach in the secondary years of compulsory, formal education, where more than half of local science teachers held adequate NOS views.

2.4. Attempts to change students' NOS conceptions

Vella Bondin (2016) argues, that "[a]lthough teachers' informed NOS understandings are a necessary prelude to translation into classroom practice, these views on their own are not sufficient due to constraining factors." (Vella Bondin, 2016, p. 194). Such a trend corroborates with international studies (Aslan et al., 2013). It was found that 'intentions towards teaching NOS' is considered the most important factor to implement NOS aspects in the classroom and one cannot simply presume that teachers would include NOS aspects because they know them

(Lederman et al., 2001).Considering this, a large number of international studies focused on using an intervention to teach the NOS. Such interventions were carried out with in-service teachers, pre-service teachers and students of various levels.

Attempts to teach the construct or as described by Deng et al. (2011) 'intervention studies' in the area may consist of teaching learning sequences. A teaching learning sequence [TLS] aims to implement a topic or a small part of a curriculum. It is "a gradual research-based evolutionary process aiming at interlacing the scientific and the students' perspective" (Meheut and Psillos, 2004, p. 515). In fact, Meheut and Psillos (2004) argue that some methodological approaches aim to evaluate "the effectiveness of a sequence by comparing the students' cognitive 'final state' with their cognitive 'initial state'." (p. 522). As seen through a number of studies (Alonso et al., 2013; Charalambous et al., 2013; Deng et al., 2011; Manassero-Mas et al., 2015) such a methodology is a widely common approach when attempting to teach the NOS, irrelevant of the framework, nature of intervention or data collection tools involved. This is usually done by giving the students a pre-test to assess their initial views. Following this, an intervention is carried out followed by a post-test. This will enable comparison and hence test the effectiveness of teaching the construct involved.

The following section targets the different pedagogical approaches that can be used to implement aspects of the NOS in the classroom.

2.4.1. Pedagogical Approach

Whatever the assessment instrument being used, there are mainly three approaches when teaching aspects of the NOS: using historical aspects of science, an implicit approach, and an explicit-reflective approach (Cepni and Cil, 2010). The following points summarise the three approaches.

- History of Science: Elements of the history of science are used to teach aspects of the NOS.
- Implicit Approach: Students will come to understand aspects of the NOS simply by doing science; no explicit reference to NOS aspects is needed.

- Explicit-reflective Approach: NOS views are directly targeted, not only as part of the lesson objectives but as a product of an amalgamation with history and philosophy of science and/ or inquiry-based activities.

a. History of Science

History of science seems to be the oldest method when it comes to implementing aspects of the NOS. In fact, Solomon et al. (1992) claim that NOS can be easily taught by using examples from the history of science. Such an approach was found to be effective in a number of studies (Fouad et al., 2015; Solomon et al., 1992). In a study in five British classrooms, history of science stories were found to improve pupils' understanding on the NOS mainly when it comes to the nature of scientific theories and experiments. Other research studies using the history of science focused on errors in science that target mainly the tentative aspect of the NOS (Allchin, 2012). Allchin (2012) claims that using historical cases of scientific error will give students and future citizens a more realistic picture of how science works and hence a better NOS understanding.

b. Implicit vs Explicit-reflective Approach

Other studies only focused on the implicit approach or simply utilising inquiry while assuming that a NOS understanding will be attained (Bell and Linn, 2000; Sandoval and Milwood, 2005). However, as claimed by one of the studies which focused on improving biology students' NOS conceptions through inquiry, "[e]ngaging students in inquiry, even as it challenges their ideas about scientific phenomena, does not seem sufficient to challenge their ideas about the nature of inquiry itself." (Sandoval and Milwood, 2005, p. 52).

Considering this,a number ofstudies compared the two approaches (Khishfe and Abd-El-Khalick, 2002; Kurdziel and Libarkin, 2002; Peters and Kitsantas, 2010). A sample of 162 eighth grade science students took part in the study carried out by Peters and Kitsantas (2010). Two science topics, namely electricity and magnetism, were taught to all students using inquiry-based activities. Further to the inquiry, the experimental group was presented with meta-cognitive prompts and explicit NOS discussions in comparison to the control group that carried out inquiry activities and discussion with no reference to NOS aspects. The study showed that the experimental group gained better understanding of the NOS and also better science content knowledge. Moreover qualitative data showed that the experimental group based its conclusions on data in contrast to the control group which tended to rely more on authority, hence the teacher, to come up with conclusions (Peters and Kitsantas, 2010).

Similarly Khishfe and Abd-El-Khalick (2002) carried out a study with 62 sixth grade students and compared NOS understanding following an explicit inquiry-oriented approach and an implicit inquiry-oriented one. The authors concluded that an explicit-reflective approach is more effective to develop informed NOS conceptions. Subsequently, a substantial number of successive studies aimed at altering students' NOS conceptions by utilising this approach were carried out (Alan and Erdogan, 2018; Celik and Bayracheken, 2006; Khishfe, 2012; Koksal et al., 2015; Kapucu et al., 2015; Quigley et al., 2010; Tsybulsky, 2017; Yildirim and Mirici, 2016).

c. Explicit-reflective approach

In another number of studies, researchers compared two types of explicit approaches: context-based and non-contextual. A context-based approach represents the NOS within a situation or circumstance where students can apply NOS content, while a non-contextual approach presents the NOS on its own. According to Marniok and Reiners (2017) the context-based approach appeared to be more effective to teach the NOS compared to its non-contextual counterpart. A number of studies also claimed that using aspects of the history and philosophy of science is important to give a context to the NOS (Marniok and Reiners, 2017; Tsybulsky, 2017). However, other authors also argued that rather than making NOS explicit, it is the follow-up reflective part about the NOS that leads to proper NOS understanding (Birkholz and Elster, 2015; Schrijver et al., 2015; Schwartz et al., 2002).

This may be due to the fact that a context will offer the students with a situation where they can apply aspects of the NOS, whilereflection will allow them to evaluate their understanding of it. According to Bloom's Taxonomy, reflection (or evaluation) is a higher order skill than application (Bloom, 1959 as cited in Armstrong, 2016). Moreover, as Schrijver et al. (2015)

argue, reflection makes way to more pluralistic views as it “is not reduced to an instrument to impregnate the teacher’s views on the NOS, but reflection rather functions as a more complex intellectual act that could help students to interpret and discuss autonomously the nature of science” (Schrijver et al., 2015, p. 793). This study argues that, although non-contextual, analogies of NOS aspects followed by a reflective part are also effective in teaching the NOS.

2.5. Assessment of the NOS

As Abd-El-Khalick (2014) puts it “a plethora of NOS assessment instruments have been developed since the early 1950’s (e.g. Wilson, 1954) and continue to be developed to the present day.”(Abd-El-Khalick, 2014, para. 4). However, it is very difficult to analyse or list these instruments as the term NOS is dynamic in nature. For example, early assessment instruments put together the cognitive, affective and attitudinal outcomes towards science.Successively, attitudes in science started to be considered as different from understandings in science.

Since 1954 a substantial number of NOS instruments has been developed. Abd-El-Khalick (2014) lists a total of 32 NOS instruments where on average two to three NOS instruments were developed over each five-year period. Out of these 32 NOS instruments a minority at 12.5% are open-ended. The majority of instruments (87.5%) are of the forced-choice type, whereby respondents select an answer or a preference, withmost of them (70%)having Likert scales. Indeed, one can argue that up to 1998 most instruments were forced-choice. Eventually open-ended instruments started to be used indicating a new direction in the field.

Moreover, earlier instruments in the field such as the Test on Understanding Science [TOUS] developed by Klopfer and Cooley (1963)were forced-choice and simply based on theoretical ideas of what comprises the NOS. Eventually instrument development became more empirically based. This includes the development of the Views of Science-Technology-Society [VOSTS] instrument. While being forced-choice, this instrument is based on empirical ideas previously attained by the authors from a representative sample of students’ ideas on the NOS (Aikenhead et al., 1992). The Views on the Nature of Science [VNOS]-Form A was introduced in 1990 while

VNOS-Form B was introduced in 1998. VNOS instruments are not forced-choice but are more open-ended in nature.

Being empirically based and forced-choice, VOSTS is one of the most popular research instruments used since its development in 1987 (Abd-El-Khalick, 2014). In fact the TOUS, VOSTS and VNOS together account for 51% of all empirical studies carried out (Abd-El-Khalick, 2014). However since 2000 new forced-choice instruments have been developed including the Scientific Epistemological Views [SEVs] (Tsai and Liu, 2005), Views on Science and Education Questionnaire [VOSE] (Chen, 2006), the SUSSI questionnaire (Liang et al., 2008) and the Nature of Science Instrument [NOSI] (Hacieminoglu et al., 2014).

Development of some of the Likert statements in the above questionnaires was based on VOSTS items and semi-structured interviews and/or results from individual interviews. Nonetheless, being forced-choice, these instruments can still be ambiguous (Abd-El-Khalick, 2014) and hence lack construct validity. The continuous development of new instruments reflects a necessity to quantify NOS understandings especially in large-scale studies (Abd-El-Khalick, 2014). Although some recent NOS evaluations highlight the importance of qualitative methods when studying NOS (Deng et al., 2011) one cannot undermine the fact that data quantification is a necessity in large-scale studies such as the one carried out here.

2.6. Conclusion

On considering this discussion, one realises that this field of study appears to be as dynamic as the term NOS itself. When taking into account the dynamic nature of the term NOS, the variety of assessment instruments used to assess it and the fact that students, undergraduates, pre-service and in-service teachers generally tend to have inadequate conceptionsof the NOS, one realises the need of ongoing research in the area. The next chapter describes the methodology used and justifies the choices made in this study.

3. Methodology

3.1. Introduction

This chapter describes the methodological approach used to answer the research questions outlined in Chapter 1 of this study. It describes the theoretical position adopted, the subsequent methods and research instruments chosen, the data collection process and how the data was eventually analysed. Finally, it also describes the difficulties encountered throughout this research process while using literature to justify the methodological decisions taken.

3.2. Choosing the Research Area

As described in Chapter 1, the aim of this study was to investigate the NOS views held by Maltese post-secondary lecturers in the various institutions in Malta. Research on the NOS in Malta is very limited, consisting of two main studies, namely those by Pace (2014) with undergraduate students and Vella Bondin (2016) with science teachers.

No study has yet investigated the NOS views held by Maltese post-secondary lecturers, who might influence the views of both undergraduate students and prospective science teachers. As Wan et al. (2011) put it, the conceptions of science teacher educators'"will have a direct bearing on the future development of science education" (Wan et al., 2011, p. 1102). Subsequently the main research question for this study was:

"What are the NOS views of Maltese post-secondary lecturers?"

For the purpose of this research the term 'post-secondary lecturers' refers to lecturers teaching in non-compulsory, formal educational institutions and therefore includes both further and higher educational institutions ("Education Act", 1991). Given the number of post-secondary institutions in Malta and subsequently the large number of post-secondary lecturers, this study incorporated the views of lecturers teaching in specific areas. This included science areas such as physics, chemistry, biology, mathematics and environmental science and science-related areas such as medicine, the health sciences, architecture and civil engineering, engineering, geography and computer studies. Lecturers in philosophy and theology and/or religious knowledge were also included in this study as, it was thought, they might make an interesting contribution when considering the different epistemologies of science and theology.

Subsequently through this study, the views of lecturers coming from various fields were investigated. These views were compared by area of specialisation, that is pure science, applied science and humanities. Science lecturers were asked to indicate their main traditional science area, i.e. Biology, Chemistry or Physics to compare their views according to this variable. NOS ideas were also compared according to age bracket, lecturing experience, gender and highest qualification.

3.3. The Research Approach

A mixed-methods approach was used to answer the research questions. Creswell (2015) describes a mixed methods research as one in which "the investigator gathers both quantitative (closed-ended) and qualitative (open-ended) data, integrates the two, and then draws interpretations based on the combined strengths of both sets of data to understand research problems." (Creswell, 2015, p. 2). Such an approach is also referred to as methodological triangulation (Flick, 2018; Greene et al., 1989) as two or more sources of data are combined to tackle the research questions. The Likert statements of the self-completion questionnaires used in this study can be considered as quantitative data while the open-ended questions of the questionnaire and the semi-structured interviews are qualitative data. Consequently, this research can be described as a between or across-method triangulation (Denzin, 1978). The main advantage of such an approach is that "it attempts to consider multiple viewpoints, perspectives, positions and standpoints" (Johnston et al., 2007, p. 113) overcoming the limitations of using a single perspective.

Given that this research study combines the two research approaches, that originated from two different paradigms (Johnston et al., 2007; Tashakkori and Teddlie, 2010), one can label the metaphysical position of this research as pragmatism. Pragmatists “focus on the practical implications of the research and will emphasize the importance of conducting research that best addresses the research problem” (Creswell, 2007, p.23).

A major challenge of mixed-methods research is “bringing together the analysis and interpretation of the quantitative and qualitative data and writing a narrative that linked the analysis and interpretation.” (Bryman, 2007 as cited in Tashakkori et al., 2010; Creswell, 2014). To overcome this issue, the quantitative findings from the questionnaire and the qualitative data were integrated as much as possible. As described in Section 3.12, the integration of data was done by collecting all types of data, analysing them separately and then merging the findings together. This is what Creswell (2015) considers as a convergent design to mixed-methods research.

3.4. The Research Strategy

The research strategy adopted in this study was the survey approach. “Typically, surveys gather data at a particular point in time with the intention of describing the nature of existing conditions” (Cohen et al., 2007, p. 205). They provide empirical, wide and inclusive coverage at a specific time (Denscombe, 2003).

The survey approach was chosen as it is economical in terms of time and money (Denscombe, 2003) and hence enabled the collection of a large number of responses within a very limited timeframe. Data generated from close-ended questions can easily be quantified and analysed, enabling the researcher to identify trends and make generalisations (Cohen et al., 2007). In fact,the major advantage of using the survey strategy is its generalisability and universality, “its ability to make statements which are supported by large data banks and its ability to establish the degree of confidence which can be placed in a set of findings” (Cohen et al., 2007, p. 207).

However, while the survey approach provides adequate external validity and reliability, it lacks depth and authenticity. As Cohen et al. (2007) put it “[i]ts degree or explanatory potential or fine detail is limited; it is lost to broad-brushed generalizations which are free of temporal, spatial or local contexts" (Cohen et al., 2007, p. 207). To compensate for this limitation, in the questionnaire, open-ended questions were used to enable participants to elaborate further on the responses expressed in the Likert statements. Additionally, semi-structured interviews were used in conjunction with the self-completion questionnaire. Through these, the construct and internal validity of findings were increased (Cohen et al., 2007).

3.5. Data Collection

Data collection for this research study occurred between September and December 2020. Once all gatekeeper permissions were reviewed and accepted by the Faculty Research Ethics Committee [FREC], data collection started. The questionnaire for UOM lecturers was distributed through the Communications Office, while questionnaires for MCAST lecturers were distributed by the directors of the participating institutes. Questionnaires for the various sixth forms were distributed via the Principal or the Head of the given college/school.

The email included the information letter together with the questionnaire link. All emails were sent between late October and mid-November;some emails were delayed to mid-November to increase response rate, since some participating institutions opened in mid-October. Given the new intake of students and the additional changes brought about by the Covid-19 pandemic, a three-week period was given for lecturers to settle down into the new routine, prior to questionnaire distribution. This was done so as to increase response rate.

In fact, questionnaire response rate was initially very low. Subsequently, additional emails were sent by the tutor and me as reminders to individual lecturers in the various institutions. Given that no hard copies could be distributed due to the Covid-19 pandemic some gatekeepers were contacted once again to resend the survey email. In this second email, it was made clear that the participant should not fill in the survey if s/he already filled it in, to avoid duplicate entries. The questionnaire was ultimately sent to a total of 1403 lecturers, with a response rate of 252. This yielded a margin of error of 5.59% at 95% confidence level.

Interview participants, on the other hand, were recruited by convenience sampling. Eventually a date and time that were convenient for the participant were set for the online interviews. Participants were also given a choice of the software to be used, since some institutions were using Zoom while others were more familiar with Microsoft Teams. All interviews were carried out online throughout November and December 2020.

3.6. The Research Participants

3.6.1. Questionnaire Participants

The questionnaire was distributed to full-time and part-time lecturers teaching specific subjects in the various Maltese sixth forms, the UOM and MCAST. Sixth form lecturers of the following subjects were considered: Biology; Chemistry; Physics; Pure Mathematics; Applied Mathematics; Geography; Computing; Environmental Science; Information Technology; Philosophy;and Religious Knowledge. The questionnaire was sent to a total of 225 sixth form lecturers.

After reviewing the MCAST Prospectus for 2020, MCAST lecturers from the following three institutes were chosen: the Institute of Applied Science; the Institute of Information and Communication Technology [ICT]; and the Institute of Engineering and Transport. The questionnaire was sent to a total of 345 MCAST lecturers.

Likewise, UOM lecturers were chosen by Faculty, Department,Institute or Centre. Participating entities were chosen if they taught science, a science-related area, philosophy or theology. Table 3.1 lists all participating UOM entities.

Faculties/ Departments	Institutes	Centres
Built Environment	Aerospace Technologies	Biomedical Cybernetics
Dental Surgery	Climate Change and Sustainable Development	Environmental Education and Research
Engineering	Earth Systems	Traditional Chinese Medicine
Health Sciences	Space Sciences and Astronomy	
Information and Communication Technology	Sustainable Energy	
Medicine and Surgery		
Science		
Theology		
Education: Department of Mathematics and Science Education (only)		
Arts: Department of Philosophy and Department of Geography (only)		

Table 3.1: UOM Faculties, Departments, Institutes and Centres included in this study

The questionnaire was ultimately distributed to a total of 833 UOM lecturers.

3.6.2. The Interview Participants

Interview participants were chosen by convenience sampling. The chosen interviewees were from different institutions and different areas of specialisation to ensure a representative sample of the general population. Table 3.2 depicts some basic demographic characteristics of interviewees.

Participant No./Code	Gender	Current Area of Teaching	Closest Traditional Science Area	Highest academic qualification	Years of Teaching Experience
Participant 1 P1	F	Physics and Mathematics	Physics	Masters	5
Participant 2 P2	M	Chemistry	Chemistry	PhD	21
Participant 3 P3	M	Theology	Humanities	PhD	8
Participant 4 P4	M	Spirituality	Humanities	PhD	22
Participant 5 P5	M	Philosophy	Humanities	PhD	24
Participant 6 P6	M	Chemistry and Biology	Chemistry	Post-graduate certificate	25
Participant 7 P7	M	Chemistry and Environmental Science	Chemistry	Masters	28
Participant 8 P8	F	Computer Studies	Physics	Masters	5
Participant 9 P9	M	Physics	Physics	PhD.	7
Participant 10 P10	M	Biology and Chemistry	Chemistry	PhD	17

Table 3.2: Basic demographic characteristics of interviewed lecturers

3.7. Research Methods

As described above two research methods were used in this research: a self-completion questionnaire and semi-structured interviews.

3.7.1. The self-completion questionnaire

The self-completion questionnaire was used to get an overall view of the NOS ideas of Maltese post-secondary lecturers. Questionnaires were considered an appropriate research tool as they are economical in terms of materials, money and time (Denscombe, 2003) and they could easily be distributed online overcoming the limitation brought about by the Covid-19 pandemic. Questionnaires also eliminate the personal effect brought about by the researcher-participant interaction while they provide standardized, pre-coded answers that are easier to analyse in the limited timeframe of this research study (Denscombe, 2003).

However, a limitation of using questionnaires is the possible low number of returns which will affect the representativeness of the sample (Cohen et al., 2007). This was enhanced by the pandemic situation as no hard copies could be distributed. Subsequently, as stated previously in Section 3.5, individual emails were sent to lecturers whose email was public while some gatekeepers were contacted again to redistribute the questionnaire. Another disadvantage of the questionnaire is that the researcher is unable to check or challenge the truthfulness of the response, unlike an interviewer would (Cohen et al., 2007; Denscombe, 2003).

a. Constructing the questionnaire

Given the complexity of the construct being tested, a ready-made questionnaire, namely the 'Student Understanding of Science and Scientific Inquiry' [SUSSI] questionnaire, was chosen for this study. This questionnaire was initially constructed, piloted and validated to test the views of older students, namely pre-service teachers (Liang et al., 2008; 2009). However, it was also used locally to test the views of practicing science teachers (Vella Bondin, 2016). Consequently, it was thought to be suitable to investigate the views of lecturers who are ultimately teachers at higher levels of education.

Demographic questions were put at the beginning of the questionnaire as these are easier to answer and will encourage the participant to proceed. The SUSSI questionnaire itself is divided into six NOS components, namely: Observations and Inferences; Change of Scientific Theories; Scientific Laws vs Theories; Social and Cultural Influence in Science; Imagination and Creativity in Scientific Investigation; and Methodology and Scientific Investigation. Each of these NOS tenets was tested using four Likert statements and an open-ended question such that the final questionnaire consisted of 24 Likert statements and six open questions.

A copy of the questionnaire can be found in Appendix A.

b. Likert Scales

A Likert scale provides a range of responses for a specific question or statement. Likert scales are "very useful devices for the researcher, as they build in a degree of sensitivity and differentiation of response while still generating numbers" (Cohen et al., 2007, p. 325). Notwithstanding, they have several disadvantages. For example, the statement might be biased towards the researcher's perspective on the issue (Denscombe, 2003). Additionally, one cannot assume that there are equal intervals between each category, and therefore one participant's 'disagree' might be equivalent to another participant's 'strongly disagree'. Moreover, considering the five-point scale used in this questionnaire, participants usually tend to opt for the middle option (Cohen et al., 2007). Another disadvantage is that one has no proof that the respondent is saying the truth and some respondents might want to add further comments (Cohen et al., 2007). In fact, the open question added after each four Likert statements could partly counteract this problem.

c. Open Questions

The open question for each of the NOS components assessed through the SUSSI questionnaire enabled respondents to elaborate further on their answers and increased the construct and internal validity of the responses. Notwithstanding, the open-questions might have discouraged some respondents from finishing the questionnaire. In fact, there was a number of participants who opted to leave them blank. Moreover, sometimes the answers provided were incomplete or had irrelevant information(Cohen et al., 2007).

d. Validation of the SUSSI questionnaire

The SUSSI questionnaire was constructed, piloted and validated by Liang et al. (2008). One way to validate an instrument is to work out the Cronbach's Alpha value to get a measure ofits internal consistency. The internal consistency of an instrument is an indication of how well it measures what it is intended to measure. The Likert statements in the SUSSI questionnaire assessing the views on specific NOS items described opposing views. Some of these statements described what is currently considered an adequate view of the NOS while other statements described what is currently considered as an inadequate view of the NOS (Liang et al. 2008). Thus, a participant which agrees with an adequate view should then disagree with an inadequate one.

The Cronbach's Alpha value uses these responses to measure the internal consistency between a number of related items or statements measuring a latent dimension or component. Thus, this value was worked out for each of the NOS components and for the whole questionnaire. The Cronbach's Alpha value ranges from 0 to 1, where the larger its value the higher is the internal consistency between the statements. Regarding Cronbach's Alpha: a value above 0.7 indicates good internal consistency; a Cronbach's Alpha between 0.5 and 0.7 indicates moderate internal consistency; and a value less than 0.5 indicates weak internal consistency. Table 3.3 shows the Cronbach's Alpha values for each NOS component and for the whole SUSSI questionnaire, based on the data obtained in this study.

NOS Item	Cronbach's Alpha Value	No. of items.
C1: Observations and Inferences	0.691	4
C2: Change of Scientific Theories	0.593	4
C3: Scientific Laws vs Theories	0.182	4
C4: Social and Cultural Influence on Science	0.755	4
C5: Imagination and Creativity in Scientific Investigation	0.843	4
C6: Methodology in Scientific Investigations.	0.359	4
Overall Questionnaire	0.787	24

Table 3.3: Cronbach's Alpha values for each NOS item and the whole questionnaire

From the statistical output, one notes that the items of components 4 and 5 have very good internal consistency, while the items of components 1 and 2 have moderate internal consistency and the items of components 3 and 6 have weak internal consistency.

This is especially evident for component 3 where the Cronbach's Alpha value is 0.182. Such a low value was also evident in the validation of this instrument. In fact, in the instrument validation Likert statement 3D and Likert statement 6D were suggested for further revision, while Likert statement 6A was revised (Liang et al., 2008). Initially I considered the idea of eliminating these statements from the analysis, however, being a ready-made tool, it was considered unethical to do so.

Subsequently while acknowledging such limitations, it was ultimately still decided to use this instrument. This was because the overall Cronbach's Alpha value for all items ultimately yielded a value of 0.787, showing an overall good score for internal consistency. Moreover, having been used in several studies (Karaman, 2017; Miller et al., 2010) including local ones (Pace, 2014; Vella Bondin 2016), it would enable better comparison of NOS views.

3.7.2. The Interview

An interview “may be defined simply as a conversation with a purpose” (Berg, 2007, p.89). Interviews were used in this research study as they provide a“greater depth” (Cohen et al., 2007, p. 352) of information, hence increasing the validity of the findings obtained through the questionnaire.

a. Constructing the interview

The interview used in this study was semi-structured. In such interviews, the questions are predetermined and are“asked in a systematic and consistent order, but the interviewers are allowed freedom to digress; that is, the interviewers are permitted (in fact, expected) to probe far beyond the answers to their prepared standardized questions.” (Berg, 2007, p. 95).

Demographic questions were placed at the beginning of the interview schedule as these are easier to answer (Patton, 1980 as cited in Cohen et al., 2007). In turn, NOS questions were developed based on the questions used in the Views on the Nature of Science [VNOS] – Form C questionnaire (Lederman et al., 2002). The interview schedule used by Vella Bondin (2016) was also consulted. Probes and prompts accompanied some of the questions. Most prompts were adopted from the VNOS-C and helped to further clarify the question. Probes helped “participants to elaborate on what they have already answered in response to a given question” (Berg, 2007, p. 102).

A major disadvantage of interviews is bias (Cohen et al. 2007; Saunders et al., 2009). The interviewer might unwillingly influence the types of responses obtained as respondents would likely provide the response that they think is expected of them. To counteract this problem, it was made clear at the beginning of the interview that there are no right or wrong answers to any of the questions. Moreover, all questions were worded in the same way and a neutral tone of voice was kept as much as possible (Saunders et al., 2009). This decreased bias ensured that questions are understood similarly, enabling better comparison. However, being a semi-structured interview, the order of questions was at times modified depending on the flow of the conversation while some probes and prompts were added or eliminated according to the specific need at the time (Berg, 2007; Saunders et al., 2009).

The interview schedule used can be found in Appendix B.

b. Online Interviews

All interviews in this study had to be carried out online using Microsoft Teams or Zoom due to the Covid-19 pandemic which would have presented a physical threat for both participant and researcher. Such interviews are known as synchronous (real-time) interviews (Berg, 2007) or virtual interviewing (Chandratre and Soman, 2020) and although not identical, are similar to a traditional, face-to-face interview enabling probing and/or modification of questions (Berg, 2007).

In fact, as O'Connor et al. (2008) argue there is very little research on synchronous, online interviewing. Many times, the complicated setting up of such interviews was the major reason why researchers opted for face-to-face interviewing (O'Connor et al., 2008). However, the Covid-19 pandemic had made most lecturers and teachers familiar with these software packages and therefore such a disadvantage was not evident. In fact, Chandratre and Soman (2020) argue that while research still needs to be done on the effectiveness of virtual interviewing, this might possibly be more economical in terms of time and money when compared to traditional interviewing. A weak internet connection, in some areas, may be a disadvantage during the interview process. Moreover, there is a greater difficulty to establish rapport (Chandratre and Soman, 2020) in an online environment. In fact, while participants had the option to turn off their video camera, I tried to leave my camera on especially at the start of the interview, to possibly establish a better rapport.

c. The Interview Participants

Interviews tend to have a higher response rate (Denscombe, 2003) when compared to questionnaires. In fact, only one participant refused to do the interview in this study. As described above, convenience sampling was used to choose participant interviewees and subsequently another possible participant was eventually contacted.

The ten interview participants were lecturers in various subjects at post-secondary level in various institutions. Participants teaching different subjects in different institutions were chosen to allow a range of views that would be more representative.

d. The Interview Process

All interviewees were contacted by email. After sharing the information letter, interested participants were asked to sign a consent form and send it back via email. Following this, they were asked to choose their preferred software between Zoom and Microsoft Teams and a convenient day and time. This ensured a familiar and convenient setting for all participants (Saunders et al., 2009).

An interview protocol (Appendix B) was prepared beforehand to help in introducing myself and giving a brief description of the purpose of the study. This helped in establishing a good rapport to subsequently encourage interviewees to participate and engage better with the interview (Holbrook et al., 2003 as cited in Bell et al., 2016; Saunders et al., 2009). Following this, all participants were reminded that interviews were going to be audio-recorded through the software used. Subsequently they were asked to make a verbal declaration that they read and understood the participant information sheet and consent to participate,prior to the interview.

All interview questions were in English. Most participants answered in English, although some of them opted to code-switch between English and Maltese.

As described above, questions were asked exactly as written in the interview schedule so as to ensure the same meaning for all participants. Moreover, “comments or non-verbal behaviour, such as gestures which indicate any bias” were avoided (Saunders et al., 2009, p. 333).Moreover, the researcher avoided projecting her own views about the subject but rather listened as much as possible to understand participant responses (Saunders et al., 2009).

3.8. Validity and Reliability

In very simple terms, validity shows “whether an item or instrument measures or describes what it is supposed to measure or describe” while reliability is “the extent to which a test or procedure produces similar results under constant conditions on all occasions” (Bell, 2005, p. 117). While various types of validity exist (Cohen et al., 2007) the questionnaire used in this study was mainly concerned with attaining reliability and what Cohen et al. (2007) describe as external validity which is “the degree to which the results can be generalised to the wider population, cases or situations” (Cohen et al., 2007, p. 136). To be able to make such generalisations, the study aimed to collect the largest possible number of responses within a limited timeframe and within the limits of the conditions of the pandemic. As described in Section 3.5, several measures were taken to ensure a more representative sample of the population (Cohen et al., 2007).

The fact that questionnaires were anonymous encouraged honesty and increased the authenticity and internal validity of responses. Additionally, a number of close-ended Likert statements were used to assess the same NOS aspect. The fact that statements explained opposite views on the same NOS aspect enabled one to validate findings by checking the internal consistency of the instrument, as seen in Section 3.7.1.3. In the related open questions participants were able to explain their responses in the corresponding Likert items, thus increasing the authenticity and internal validity of findings (Cohen et al., 2007).

Interviews were also used to support questionnaire findings. In fact, the convergent design used in this study enabled a higher validity of both questionnaire and interview findings as the findings of one method could be used to confirm or refute those of the other (Creswell, 2014). Such an approach increases concurrent validity as “the data gathered from using one instrument must correlate highly with data gathered from using another instrument” (Cohen et al., 2007, p. 140). Additionally, while constructing the interview schedule, it was ensured that interview questions assessed NOS tenets similar to those of the SUSSI questionnaire. This enabled better alignment of data from the two sources (Creswell, 2014), as seen in Section 3.12.

3.9. Piloting

A pilot study can be described as a small-scale study of the actual research which "helps the researcher to focus and adapt the research better to the local situation" (Gudmundsdottir and Brock-Utne, 2010, p. 360). Due to Covid-19 restrictions, piloting of both the questionnaire and the interview had to be carried out remotely. Thus, the questionnaire was sent to twelve possible participants. Following this, the data collected was analysed to ensure that it answered all the research questions proposed. A slight change was made to one of the demographic questions where participants had to choose their closest traditional science area. The category 'Humanities' was added as some lecturers, especially those with a humanities background, might have no background in any traditional science area. The NOS questions appeared to have answered the major research questions, and no modifications were made in this regard.

In turn, the interview was piloted with a sixth form lecturer. The participant was made aware that the interview was being carried out for piloting purposes. At the end of the interview the participant was asked to make any suggestions for amendments. However, the participant said that she was able to answer all questions and therefore no modifications were made. Subsequently this interview was added with the data used in this study.

Following piloting, the required permission to carry out the research in the various institutions had to be obtained.

3.10. Access to the Research Field

After obtaining approval for my research proposal, ethical clearance had to be obtained. This was done by submitting an application to the Faculty Research Ethics Committee [FREC], which consisted of a summary of the purpose of the research together with details on respondents' participation. A copy of both the questionnaire and interview together with the required permission letters, information sheets and consent forms were submitted.

Following approval from FREC, permissions from the various institutions had to be obtained. The Directorate for Research, Lifelong Learning and Employability, the Secretariat for Catholic Education, the MCAST Ethics Committee and the Human Resources Department at the UOM were initially contacted by email.

A formal research request form was required by the Directorate, a research application was needed by the MCAST Ethics Committee while emails were sent to the Secretariat for Catholic Education, the Human Resources at the UOM and Heads of independent sixth forms. Following permissions from the various institutions, a permission letter was sent by email to Principals and/or Heads of sixth forms andDirectors of participating institutes at MCAST. A copy of all permission letters can be found in Appendix C. All permissions were obtained after a month and a half.

The final stage of ethical clearance required the submission of all permissions to the FREC who also granted their approval.

Once permission to start the collection of data was obtained one needed to consider some ethical issues involved in collecting data. Consideration was given to granting a fully comprehensive, informed consent while keeping the time required for participation as short as possible. This was especially important when considering the exceptional circumstances brought about by the Covid-19 pandemic, which caused changes in the working routine for most lecturers.

3.11. Ethical Issues

Ethical issues are an important part of research and should be anticipated and addressed during every stage of the research process (Creswell, 2014). Ethical issues were considered prior to the commencement of the study by consulting both the General Data Protection Regulation [GDPR] (European Union, 2016) and the guidelines published by FREC (Faculty of Education 2019; UOM

2019a; 2019b), since being ethical goes beyond simply obtaining permission to conduct the research study.

Once institutional permissions were obtained, questionnaires including an information letter were distributed. A copy of this letter can be found in Appendix A. Anonymity in the questionnaire responses was ensured as no personal questions were asked. Additionally, these were done online using Google Forms which does not collect IP addresses. This eliminates participant traceability.

Information letters and consent forms were also distributed to interview participants. Due to Covid-19 restrictions, this had to be done via email. Subsequently it was made sure that the information letter included a very clear description of the study and how data will be collected and used in the write-up of this study. Participants were also informed that their participation is fully voluntary, that they can refrain from answering specific questions and/or withdraw from the study at any time. It was also made sure that audio-recorded interviews were password protected and were only accessed by the researcher.

Care was taken to ensure that all interview participants and their institution remained anonymous in the dissertation write-up. While excerpts of interviews and open responses were used, it was made sure that these were not presented in an identifiable form to eliminate traceability. The information letter and consent form for the interview can be found in Appendix D.

3.12. Data Analysis

3.12.1. The Questionnaire

Questionnaire data was initially downloaded from Google Forms into a Microsoft Excel 2016 file. Then incomplete responses were eliminated such that a total of 252 responses were used in the final analysis. To carry out the actual analysis, the data was transferred to SPSS Statistics which was used in the final analysis of both the open and close-ended responses of the SUSSI questionnaire.

a. Close-ended responses

The SUSSI questionnaire consisted of six NOS components namely: Observations and Inferences; Change of Scientific Theories; Scientific Laws vs Theories; Social and Cultural Influence on Science; Imagination and Creativity in Scientific Investigation; and Methodology and Scientific Investigation. Each of these components was assessed by four close-ended Likert statements.

Initially each of these statements was denoted by a '+' or a '–' sign. Positive statements described an adequate view while negative statements described an inadequate view on the given NOS component. A rubric describing an adequate and an inadequate view on each NOS component can be found in Appendix E.

Each Likert statement was numbered. Positive statements were numbered from 1 to 5, where a score of 1 would indicate that the participant strongly disagrees with the statement while a score of 5 indicates that the participant strongly agrees. Negative statements were numbered in the reverse order, from 5 to 1, such that a score of 5 would indicate that the participant strongly disagrees while a score of 1 would indicate that the participant strongly agrees with the statement. This follows the analysis used by Miller et al. (2010). Eventually the mean score for each NOS component was worked out, together with the overall mean, such that the higher the value of the mean, the more adequate the view of the participant will be (Miller et al. 2010). Mean scores could subsequently be classified. Values between 0.00 and 2.49 showed an inadequate view, values between 2.50 and 3.49 showed an intermediate or transitional view while values of 3.50 or higher showed an adequate view.

Further analysis was carried out by looking at the scores of the individual Likert statements. Here a score of 1 or 2 was considered as an inadequate view while a score of 4 or 5 was considered as an adequate view. A score of 3 was considered as an intermediate or transitional view. Frequency tables, percentages and bar graphs were then used to represent this data.

Statistical tests were then used to determine significant differences between various subgroups namely according to gender, age group, lecturing experience, area of specialisation,closest traditional science area, and highest qualification. Initially, chi square analysis, which compares the above response categories (adequate, inadequate and transitional) for each demographic variable, was worked out. However, chi square analysis is usually accompanied by a separate descriptive table for each NOS component showing the percentage of each view in each subgroup within the demographic variable. Considering the large number of demographic variables in this study, the number of descriptive tables would have been enormous. Thus, it was decided to use another statistical test which would merge the descriptive table and graph of all components while showing the same result.

Two available tests that compare the mean values obtained in various independent subgroups are the One-way ANOVA test and the Kruskal-Wallis test. Unlike the chi square test, which uses categories, these tests use the mean which is a numerical variable that has a distribution. Thus, normality tests, namely the Kolmogorov-Smirnov and the Shapiro-Wilk tests, had to be carried out to identify the best statistical test between the two. The following null and alternative hypotheses were used:

- The null hypothesis specifies that the score distribution is normal and is accepted if the *p* value exceeds the 0.05 level of significance.

- The alternative hypothesis specifies that the score distribution is skewed (violates the normality assumption) and is accepted if the *p* value is less than the 0.05 level of significance.

All *p* values violated the normality assumption in both tests indicating a skewed distribution,and therefore a non-parametric test had to be used. The Kruskal-Wallis test was therefore chosen to compare the mean values obtained in the various subgroups. The following null and alternative hypotheses were used:

- The null hypothesis specifies that the mean scores vary marginally between the groups and is accepted if the *p* value exceeds the 0.05 level of significance.

- The alternative hypothesis specifies that the mean scores vary significantly between the groups and is accepted if the *p* value is less than the 0.05 criterion.

Through this test, the mean scores of all components for the various subgroups could be compared. A descriptive table and an error bar graph were used to represent this data. Error bars were included in the graphs to easily depict similarities or differences between subgroups. Post hoc analysis for this test was also carried out for significant differences in demographic variables with more than two subgroups. This made pairwise comparisons between the groups indicating where the difference is statistically significant.

b. Open-ended responses

Since a considerable number of participants answered the open questions it was decided to convert this qualitative data into quantitative data to further substantiate the findings from the close-ended items. The rubric in Appendix E, which was developed by the authors of the questionnaire and was used to classify open responses in Miller et al. (2010), was used. Based on this rubric, adequate views were given a score of 3, intermediate or transitional views were given a score of 2 while inadequate views were given a score of 1. Views which could not be classified based on the rubric descriptions, were not completed or did not address the prompt were denoted by a score of 0.

A frequency table was then used to combine open and closed responses while a statistical test was used to show if the scores of the open responses agreed with the scores of the close-ended responses. Considering that both responses had an ordinal scale the Kendall's tau-b test was worked out. The following null and alternative hypotheses were used:

- The null hypothesis specifies that there is no agreement between the responses of close-ended and open-ended and is accepted if the *p* value exceeds the 0.05 level of significance.

- The alternative hypothesis specifies that there is agreement between the responses of close-ended and open-ended questions and is accepted if the *p* value is less than the 0.05 criterion.

Considering the multiple groups in some demographic variables which yielded a low number of open responses, in some subgroups quantitative treatment of open responses was only used when looking at the views of all participants. Only excerpts of these responses were used to substantiate the findings when comparing the views of various subgroups.

3.12.2. Interviews

As suggested by Saunders et al. (2009) all audio-recorded interviews were transcribed on the same day that the interview was carried out. This ensured a better record of the exact explanations given and general points of value (Saunders et al. 2009). Interview data was initially transcribed on a Microsoft Word 2016 document. Interview analysis was then carried out in two ways.

Initially the interviews were read several times to make sense of the overall view expressed by each participant. Eventually all responses to a specific question were pasted on a separate word document and printed. Inductive coding or open coding (Denscombe, 2003; Medelyan, 2020) was then used to identify codes for each question which were written in the margins. These codes usually consisted of specific words or ideas that commonly occurred in responses (Denscombe, 2003). This process was carried out systematically as described by Medelyan (2020).

Once these codes were identified,“patterns and processes, commonalities and differences” had to be identified (Denscombe, 2003, p. 272). This was done by categorizing these codes. Some codes were merged while others were linked, many times, in a hierarchical way - what Medelyan (2020) describes as a hierarchical coding frame. When codes were merged, each individual response was reviewed again to ensure that the code actually depicted the view expressed in each response. Eventually reflection on these emerging coding frames was done to develop a set of emerging themes from each question (Denscombe, 2003).

Considering that the interview data had to be merged with quantitative data from close-ended and open-ended questions one had to make sure to align this data well to increase the validity of findings (Creswell, 2014). Given that most interview questions were directly linked to the NOS tenets assessed by the SUSSI questionnaire, an overall analysis of the views of each participant was also carried out. This entailed seeing all responses from a specific participant as a whole and identifying the views as adequate, inadequate or intermediate based on the rubric of the SUSSI questionnaire found in Appendix E. This process could be done for most components and helped the researcher to better align the quantitative and qualitative findings. Such a process was carried out after inductive coding to ensure that other themes and/or ideas on the NOS will also emerge.

3.13. Difficulties Encountered during the Research

The major difficulty encountered in this research study was the timeconstraint brought about by the Covid-19 pandemic. As described in Chapter 1, the initial proposal of this dissertation had to be changed completely due to the limited ways through which data could be collected during this time. Subsequently, although the same area was kept, a completely new proposal had to be submitted in May 2020. This meant that the dissertation had to be carried out in a shorter period of time.

An additional difficulty came about when collecting the data. The issue of permissions and subsequent approval to start collecting data coincided with the opening of some institutions. As described in Section 3.5, due to this, questionnaire distribution had to be further delayed for some institutions. Additionally, because of the extraordinary circumstances of the academic year ahead, participant lecturers were facing new challenges and had to devise new ways to teach and adapt their work. This made it difficult to obtain a large number of responses as participants had a busier schedule. Moreover, hard copies could not be distributed due to the pandemic, which further limited the number of responses that could be obtained. As described in Section 3.5, additional emails were eventually sent as reminders to increase the sample size.

Eventually a sufficient number were collected, and a considerable degree of representativeness was obtained.

3.14. Conclusion

In this chapter, the methodology employed throughout this research process was discussed, while the strengths and limitations of the study were elucidated. Literature was also considered to justify the methodological decisions taken.

In the next chapter, the results of this research study will be presented, analysed and eventually discussed.

4. Results and Discussion of Results

As Miller et al. states: “Science educators have the common goal of helping students develop scientific literacy, including understanding of the nature of science (NOS)” (Miller et al., 2010, p. 45). The purpose of this research study is to purport a better insight on the views on the NOS of post-secondary educators in the various institutions in Malta. This chapter shall describe the analysis and discussion of these results and will ultimately give an overview of the outcomes.

It is divided into two major sections:the first section will present the results for all participants, while the second section will include the results by gender, age group, lecturing experience, area of specialisation, closest traditional science area and highest qualification respectively.

These analyses combine responses from three sources, namely the close-ended Likert statements, the open-ended responses and interview data. Tables, graphical representations, and statistical tests shall be used to represent quantitative data together with excerptsrepresenting qualitative data.

4.1. Views of all participants

This section shall be divided into six sections. Every section will represent each of the six SUSSI components, namely: Observations and Inferences; Change of Scientific Theories; Scientific Laws vs Theories; Social and Cultural Influence on Science; Imagination and Creativity in Scientific Investigations; and Methodology in Scientific Investigations.

4.1.1. Component 1: Observations and Inferences

This component consisted of the following four Likert statements and open-ended question:

A. Scientists’ observations of the same event may be different because the scientists’ prior knowledge may affect their observations.

B. Scientists' observations of the same event will be the same because scientists are objective.

C. Scientists' observations of the same event will be the same because observations are facts.

D. Scientists may make different interpretations based on the same observations.

Explain why you think that scientists' observations and interpretations of the same event are the same OR different? You may provide examples to support your answer.

According to Liang et al. (2009) as cited in Miller et al. (2010) an adequate view on this component shows that the participant believes that scientists' observations and interpretations may be different due to their prior knowledge and/or perspectives in current scientific knowledge. In turn, an inadequate view shows that the participant thinks that scientists' observations and/or interpretations are the same because scientists are objective (Liang et al., 2009 as cited in Miller et al., 2010). Therefore, statements 1A and 1D were considered positive as they represent an adequate view while statements 1B and 1C were considered negative as they represent an inadequate view. A transitional or intermediate view in turn shows that the participant thinks that either the observation or the inference may be different, but not both (Liang et al., 2009 as cited in Miller et al., 2010).

Table 4.1 and Figure 4.1 show the views of all participants based on the mean for Component 1 [C1], while Table 4.2 shows the views of all participants for each individual Likert statement on C1.

C1: Observations and Inferences			
		Frequency	Percentage
Valid	Inadequate	16	6.3
	Intermediate	78	31.0
	Adequate	158	62.7
	Total	252	100.0

Table 4.1: Views of all participants based on the mean for C1

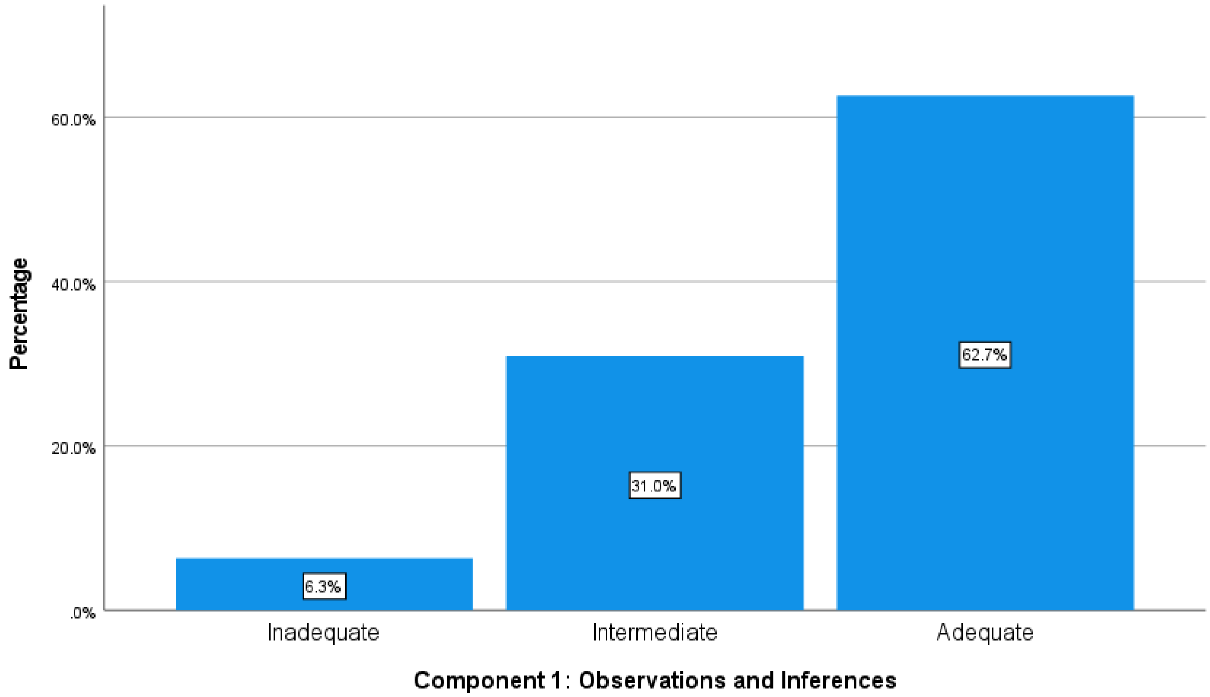

Figure 4.1: A bar graph showing the percentage of views based on the mean for C1

	Inadequate		Intermediate		Adequate		Total	
	N	%	N	%	N	%	N	%
1A: Scientists' observations of the same event may be different because the scientists' prior knowledge may affect their observations.	69	27.4%	16	6.3%	167	66.3%	252	100.0%
1B: Scientists' observations of the same event will be the same because scientists are objective.	90	35.9%	37	14.7%	124	49.4%	251	100.0%
1C: Scientists' observations of the same event will be the same because observations are facts.	70	27.9%	31	12.4%	150	59.8%	251	100.0%
1D: Scientists may make different interpretations based on the same observations.	10	4.0%	9	3.6%	232	92.4%	251	100.0%

Table 4.2: Views of all participants for each Likert statement on C1

One notes that62.7% of Maltese lecturers had adequate views on C1, 31.0% had intermediate views while only 6.3% had inadequate views. Such a result corroborates what was found by Vella Bondin (2016) and Pace (2014) who used the SUSSI questionnaire to study the NOS views of Maltese secondary science teachers and Maltese undergraduates respectively. Vella Bondin (2016) found that 70.8% of Maltese science teachers had adequate views on observations and inferences while Pace (2014) found that 66.9% of Maltese undergraduates have adequate views on this component. It is interesting to note that, in general, Maltese post-secondary lecturers had a lower percentage of adequate views on this component when compared to both science teachers and undergraduates.

Moreover, if one looks at the individual Likert sub-scales'outcomes (Table 4.2) one notes that most participants have a high percentage of adequate views when compared to the percentages of inadequate and intermediate views on the same statement. However, while 92.4% of participants agreed that scientists' interpretations may be subjective (1D), only 66.3% agreed that observations can also be subjective (1A). Similar results were found by Vella Bondin (2016), Pace (2014) and Liang et al. (2009). This may indicate that while the majority of participants recognize the subjectivity of inferences, a much lower percentage recognize the subjectivity of observations. This result corroborates the responses to the open-ended item for C1.

Table 4.3 displays the views of all participants for both the open-ended item and the close-ended item. The Kendall's Tau-b test was used to investigate the agreement between the two types of responses. This test was used because both responses had an ordinal scale ranging from inadequate to intermediate to adequate. For the purpose of this test:

- The null hypothesis specifies that there is no agreement between the close-ended and the open-ended responses and it is accepted if the *p* value exceeds the 0.05 level of significance.
- The alternative hypothesis specifies that there is agreement between the responses for the close-ended and open-ended questions and it is accepted if the *p* value is less than the 0.05 criterion.

These null and alternative hypotheses shall be used for the Kendall'sTau-b test for the analysis of all the SUSSI components.

			C1:(Open-ended Response)			Total
			Inadequate	Intermediate	Adequate	
C1:(Close-ended Response)	Inadequate	N	7	2	3	12
		%	4.3%	1.2%	1.9%	7.5%
	Intermediate	N	7	25	11	43
		%	4.3%	15.5%	6.8%	26.7%
	Adequate	N	1	48	57	106
		%	0.6%	29.8%	35.4%	65.8%
Total		N	15	75	71	161
		%	9.3%	46.6%	44.1%	100.0%
Kendall's Tau-b = 0.356, p < 0.001						

Table 4.3: Views of all participants on the close-ended and open-ended responses for C1

Considering the total percentages of each open-response, 46.6% of participants had intermediate views, followed closely by 44.1% of participants that had adequate views, withonly 9.3% of participants having inadequate views. Such a result corroborates what was found by Liang et al. (2006), where the open responses of the SUSSI yielded a lower percentage of adequate views when compared to their close-ended counterpart. The authors suggestedthat this may have happened because of the stringent scoring guide that required participants to recognise the subjectivity of both observations and inferences for the view to be classified as adequate. Most participants"discussed either observations or inferences but failed to address both in their constructed responses" (Liang et al., 2006, p. 15). In fact, most open responses in this study reflect the result obtained in the close-ended items as participants tended to mention inferences as being subjective, while very few participants said that observations can also be subjective. Subsequently the Kendall's Tau-b*p* value obtained was less than 0.001 showing agreement between the responses for the close-ended and open-ended items.

Interview findings yielded similar results. Participants were asked if different scientists can interpret the same set of data differently. Therefore, responses were primarily based on the nature of inferences. Allten participants agreed that scientists can interpret the same data differently, and hence inferences can be different, at least to some extent. Such a result is similar to that obtained by Vella Bondin (2016) where all secondary school science teachers agreed that scientists can make different interpretations based on the same observations. However, in this study two of the participants appeared sceptic about this. One participant said that this should not happen in areas where mathematics is involved while the other participant said that science aims to be objective and therefore this should not happen. Excerpts of these responses are shown below.

> *"You know science, they like to talk about objectivity. To be objective it has to be true for everybody, the same, the same results for everybody to be objective. So, if there are discrepancies then they panic. If you take, I don't know, a drug for the virus they do experiments and in one laboratory in Malta they work, everybody cured. And another laboratory in Malta with the same drugs you know everyone got sick then you know the result isn't conclusive, isn't objective. They would have to check and usually, usually I mean that's why there are scientific procedures on how to conduct the experiments, to avoid this kind of thing."*
>
> (P5: 3/11/2020)

> *"There are certain facts which I think would remain standardised. It's like in mathematics if we have a certain addition 1 +1 is always equal to 2 even though you might look at it from different perspectives or different people might look at it."*
>
> (P8: 10/11/2020)

It is interesting to note that one participant has no background in any of the traditional science subjects, that is chemistry, biology and physics, while the other participant only has Physics at Advanced level. Such lack of science education may have effected participants' views on this component. Nonetheless, considering the global results, one can still argue that the majority of Maltese lecturers have transitional to adequate views on the subjective nature of both observations and inferences.

4.1.2. Component 2: Change of Scientific Theories

The following four Likert statements and open-ended question were used to assess the views on this NOS component:

A. Scientific theories are subject to on-going testing and revision.

B. Scientific theories may be completely replaced by new theories in light of new evidence.

C. Scientific theories may be changed because scientists reinterpret existing observations.

D. Scientific theories based on accurate experimentation will not be changed.

Explain why you think scientific theories change OR do not change over time? You may provide examples to support your answer.

An adequate view on this component shows that the participant thinks that scientific theories may change in light of new evidence or by the reinterpretation of existing evidence (Liang et al., 2009 as cited in Miller et al., 2010). Subsequently, statements 2A, 2B and 2C were considered positive. An intermediate view in turn shows that the participant thinks that scientific theories may change only in light of new evidence or experimental outcomes but not by the reinterpretation of existing evidence. An inadequate view in turn shows that the participant thinks that scientific theories do not change as they are based on accurate experiments or facts. Thus, statement 2D was considered negative.

Table 4.4 and Figure 4.2 show the views of all participants based on the mean value obtained for Component 2 [C2]. Table 4.5 in turn depicts the results based on the individual Likert sub-scales.

C2: Change of Scientific Theories			
		Frequency	Percentage
Valid	Inadequate	6	2.4
	Intermediate	25	9.9
	Adequate	221	87.7
	Total	252	100.0

Table 4.4: Views of all participants based on the mean for C2

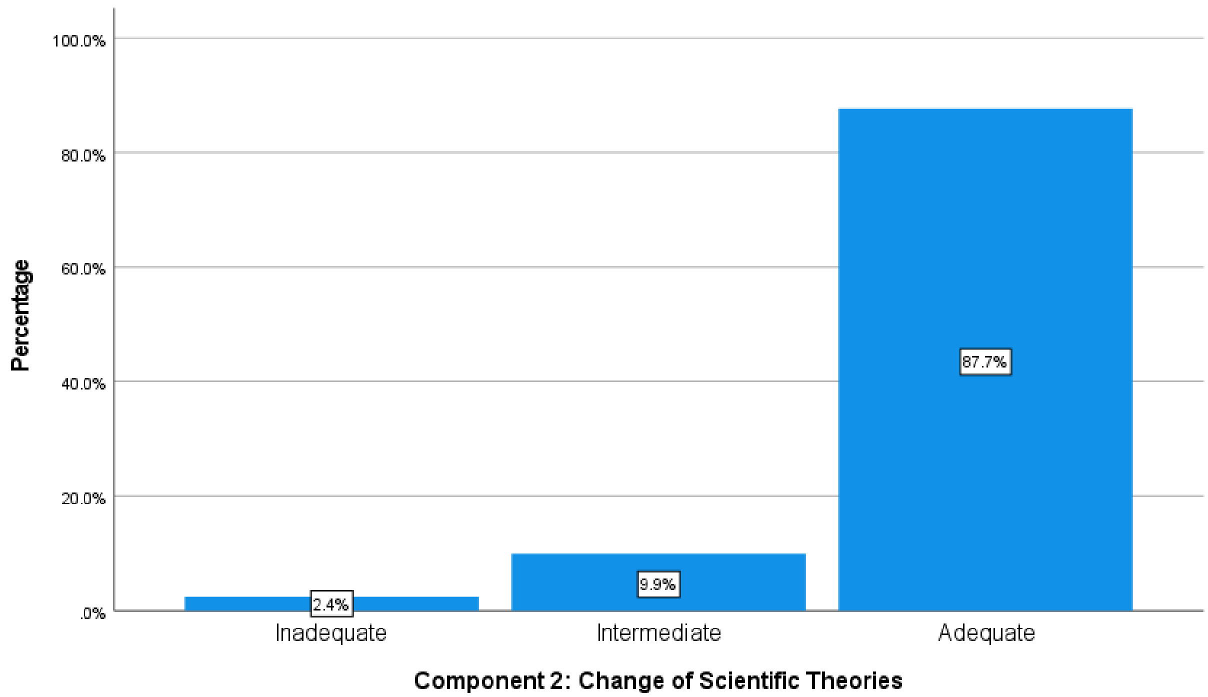

Figure 4.2: A bar graph showing the percentage of views based on the mean for C2

	Inadequate		Intermediate		Adequate		Total	
	N	%	N	%	N	%	N	%
2A: Scientific theories are subject to on-going testing and revision.	14	5.6%	11	4.4%	227	90.1%	252	100.0%
2B: Scientific theories may be completely replaced by new theories in light of new evidence.	12	4.8%	12	4.8%	227	90.4%	251	100.0%
2C: Scientific theories may be changed because scientists reinterpret existing observations.	32	12.7%	30	11.9%	190	75.4%	252	100.0%
2D: Scientific theories based on accurate experimentation will not be changed.	55	22.0%	41	16.4%	154	61.6%	250	100.0%

Table 4.5: Views of all participants for each Likert statement on C2

Table 4.4 shows that 87.7% of participants had an adequate view on this component followed by 9.9% with an intermediate view and 2.4% having an inadequate view. This clearly indicates that most participants have adequate views on the change of scientific theories. Furthermore, similar trends were observed when looking at the Likert sub-scales where more than 60% of participants expressed adequate views on all Likert statements. Similar results were obtained in a study conducted with practicing university research chemists which concluded that all fifteen participating scientists implied that “scientific knowledge is tentative and subject to change"(Sandoval and Redman, 2015, p. 1092). Such a result is also congruent with the findings of both Vella Bondin (2016) and Pace (2014) who reported 92.7% of adequate views for secondary science teachers and 88.5% of adequate views for undergraduates respectively. Once again, it is interesting to note that undergraduates and secondary science teachers had slightly higher percentages of adequate views on this component when compared to Maltese lecturers.

Further analysis of this component was carried out by analyzing the open-ended responses. Table 4.6 combines the results for both the open-ended and close-ended items.

			C2:(Open-ended Response)			Total
			Inadequate	Intermediate	Adequate	
C2:(Close-ended Response)	Inadequate	N	3	1	0	4
		%	1.9%	0.6%	0.0%	2.5%
	Intermediate	N	3	10	0	13
		%	1.9%	6.3%	0.0%	8.1%
	Adequate	N	6	111	26	143
		%	3.8%	69.4%	16.3%	89.4%
Total		N	12	122	26	160
		%	7.5%	76.3%	16.3%	100.0%
Kendall's Tau-b = 0.305, p = 0.01						

Table 4.6: Views of all participants on the close-ended and open-ended responses for C2

When looking at the total percentages of open-responses one can notice that 76.3%, that is over three fourths of participants, had intermediate views, followed by 16.3% of adequate views and 7.5% of inadequate views. Such a finding may be attributed to the fact that an informed view required respondents to specify that theories may change due to the reinterpretation of existing evidence (Liang et al., 2009 as cited in Miller et al., 2010). While most participants in this study agreed that theories changed, most of them simply stated that they change in light of new evidence, experiments or technology. According to the rubric this had to be classified as an intermediate view (Liang et al., 2009 as cited in Miller et al., 2010), and subsequently such a stringent criterion yielded a higher percentage of intermediate views when considering open responses. Such a finding is also partly corroborated in the close-ended responses where 90.4% of participants agreed that theories change in the light of new evidence

(2B) compared to 75.4% who agreed that this may happen due to the reinterpretation of existing evidence (2C). Subsequently the Kendall's Tau-b test had a *p* value of 0.01 confirming that there is an agreement between the scores of open-ended and close-ended items.

For the interview responses, eight out of ten participants agreed that scientific theories change. The two other participants also agreed that some scientific theories may change but said that some theories do not. Seven of the participants who said that theories change also said, or at least implied, that this happens due to new evidence, data, knowledge or observations. However only two participants, namely P3 and P4, said that theories also change due to the reinterpretation of existing evidence. Such a result reflects the responses for the open questions. Excerpts from these interview responses are shown below.

> *"I think they need to be tweaked and new interpretations come up and new understanding undoubtedly. I can see how this can happen with new knowledge, new knowledge gives us better understanding of old models and old perceptions."*
>
> (P3: 3/11/2020)

> *"Any theory can be challenged by new data coming up, by new approaches being tested."*
>
> (P4: 3/11/2020)

Thus, the interview results show that in line with Maltese undergraduates (Pace, 2014) and Maltese secondary science teachers (Vella Bondin, 2016) most Maltese lecturers tend to recognise the tentative nature of scientific theories. Such a finding is also similar to that obtained by Irez (2006) who studied the NOS views of pre-service teacher educators, hence lecturers, in Turkey. Similarly, in this study all lecturers recognised that theories may change due to new evidence, however only 53% recognised that this may happen due to the reinterpretation of existing evidence.

4.1.3. Scientific laws vs theories

The questions for this component were the following:

A. Scientific theories exist in the natural world and are uncovered through scientific investigations.

B. Unlike theories, scientific laws are not subject to change.

C. Scientific laws are theories that have been proven.

D. Scientific theories explain scientific laws.

Explain what are scientific theories and scientific laws and how they are different. You may provide examples to support your answer.

A scientific theory is a well-substantiated explanation of a natural phenomenon (Liang et al., 2008) that does not necessarily exist in nature while a scientific law is a description of a generalised relationship, usually mathematical, of natural phenomena under a set of conditions (Lederman, 2007; Liang et al., 2008). An adequate view on this component shows that the participant thinks that scientific theories and scientific laws are two distinct forms of knowledge which are both subject to change (Liang et al., 2009 as cited in Miller et al., 2010). An inadequate view in turn indicates that the participant thinks that scientific laws are more certain than theories or that theories develop into laws when they are proven. Therefore, statements 3A, 3B and 3C were considered negative while statement 3D was considered positive. An intermediate view in turn indicates that the participant thinks that scientists find theories or laws in nature but is unable to distinguish between them (Liang et al., 2009 as cited in Miller et al., 2010).

Table 4.7 and Figure 4.3 show the mean results for Component 3 [C3] while Table 4.8 provides the results on the individual Likert statements.

C3: Scientific Laws vs Theories			
		Frequency	Percentage
Valid	Inadequate	42	16.7
	Intermediate	157	62.3
	Adequate	53	21.0
	Total	252	100.0

Table 4.7: Views of all participants based on the mean for C3

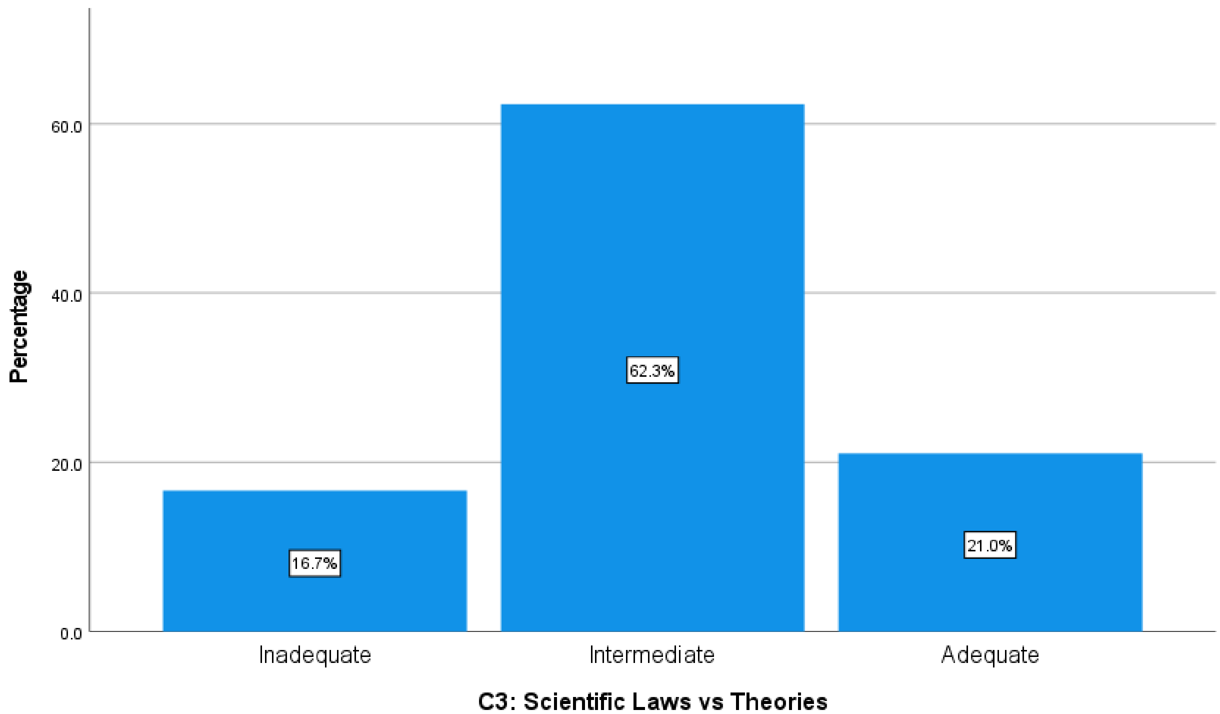

Figure 4.3: A bar graph showing the percentage of views based on the mean for C3

	Inadequate		Intermediate		Adequate		Total	
	N	%	N	%	Count	%	N	%
3A: Scientific theories exist in the natural world and are uncovered through scientific investigations.	166	66.1%	22	8.8%	63	25.1%	251	100.0%
3B: Unlike theories, scientific laws are not subject to change.	119	47.4%	38	15.1%	94	37.5%	251	100.0%
3C: Scientific laws are theories that have been proven.	149	59.4%	36	14.3%	66	26.3%	251	100.0%
3D: Scientific theories explain scientific laws.	50	20.1%	48	19.3%	151	60.6%	249	100.0%

Table 4.8: Views of all participants for each Likert statement on C3

Table 4.7 and Figure 4.3 show that most participants (62.3%) have intermediate views on scientific laws vs theories, followed by 21.0% of adequate and 16.7% of inadequate views. A high percentage of intermediate views on this component corroborates what was found by both Vella Bondin (2016) and Pace (2014). However, it is interesting to note that Pace (2014) reported 9.5% while Vella Bondin (2016) reported 17.3% of adequate views among undergraduates and science teachers respectively. In both studies, the percentage of inadequate views on this component was higher when compared to the percentage of adequate views. In this study, Maltese lecturers were found to have a higher percentage of adequate views (21.0%) when compared to both studies and this also supersedes the percentage of inadequate views (at 16.7%) in this study. This indicates that Maltese lecturers tend to have better views on this component than both Maltese science teachers and undergraduates.

The individual Likert sub-scales show that statements 3A, 3B and 3C have a high percentage of inadequate views, indicating that most participants think that scientific theories exist in the natural world and are uncovered through scientific investigation (3A). Moreover, 59.4% of participants also think that scientific laws are theories that have been proven (3C) while 47.4% think that laws do not change (3B). Similar findings on the distinction between laws and theories were obtained in other studies carried out with different populations including students (Miller et al., 2010; Pace, 2014; Parker et al., 2008), teachers, lecturers (Irez, 2006; Karaman, 2017; Liang et al., 2008; Vella Bondin, 2016) and scientists (Bayir et al., 2014; Wong and Hodson, 2008). Such a result was also corroborated with the responses obtained from the open-ended item. Table 4.9 combines responses from the close-ended and open-ended questions.

			C3: Scientific Laws vs Theories (Open-ended Response)			Total
			Inadequate	Intermediate	Adequate	
C3: Scientific Laws vs Theories (Close-ended Response)	Inadequate	N	14	4	0	18
		%	16.3%	4.7%	0.0%	20.9%
	Intermediate	N	42	8	0	50
		%	48.8%	9.3%	0.0%	58.1%
	Adequate	N	4	10	4	18
		%	4.7%	11.6%	4.7%	20.9%
Total		N	60	22	4	86
		%	69.8%	25.6%	4.7%	100.0%
Kendall's Tau-b = 0.389, p <0.001						

Table 4.9: Views of all participants on the close-ended and open-ended responses for C3

As one can notice in the open-ended item, 69.8% of participants had an inadequate view, followed by 25.6% and 4.7% with intermediate and adequate views respectively. Once again, the Kendall's Tau-b *p* value indicates an agreement between the two types of responses. Such a high percentage of inadequate views may be attributed to the fact that in the open-ended response participants often referred to the hierarchical relationship between laws and theories, stating that laws are more certain than theories. In fact, as seen in Table 4.9, 48.8% of participants that expressed an intermediate view in the close-ended response explained an inadequate view in the open-ended item. Interestingly, such a hierarchical relationship is also evident in practicing scientists (Bayir et al., 2014; Wong and Hodson, 2008) and prospectivelecturers (Irez, 2006). Bayir et al. (2014) report that almost half of practicing social and natural scientists keenly defended this naïve view. Other authors argued that the term 'law' may misconstrue its tentative nature due to the everyday use of the term (Parker et al., 2008; Wong and Hodson, 2008). Such an idea was evident in the response of one of the interviewees who found it difficult to answer this question as she had little background in the natural sciences. She said:

> *"I believe that a law is more sure than a theory. Because I think even in general laws are…everyone has to abide by the laws which are in place. So, for sure laws are...I think they are more...a law is stronger than a theory."*

(P8: 10/11/2020)

Other interview participants expressed similar naïve views on the distinction between laws and theories. In fact, eight out of ten participants said that laws are more certain than theories with two of them agreeing that laws do not change. Three participants also said that a theory develops into a law. The following are examples of such views from various disciplines:

> *"As you move from hypothesis, to theory, to law, the level of certainty increases."*

(P7: 7/ 11/2020)

> *"The theory example…you know you get a lot of data, information I don't know, you see the apple falling to the ground and you theorise why does it …you try to put the facts together to make sense of them and then as a result of that theory you come up with the idea that there's a law of nature."*

(P5: 3/ 11/2020)

> *"I think a law is a theory which is proven."*

(P8: 10/11/2020)

It is interesting to note that out of all respondents only one participant gave the proper definition of a scientific law:

> *"A scientific law is based on observable facts. And it is usually a mathematical relationship. It can be described by a formula."*
>
> (P6: 4/11/2020)

Such findings make one realise that many times even professionals who work in science are not aware and rarely think about such definitions. Considering this, as Wong and Hodson (2008) argue, one should rethink the use of the term 'law' "because it is a confusing term that indicates an unjustifiable status as "definitive and not subject to change."" (Wong and Hodson, 2008, p. 122).

4.1.4. Social and Cultural Influence on Science

The following Likert statements and open-ended question were used to assess the views on this component:

A. Scientific research is not influenced by society and culture because scientists are trained to conduct pure, unbiased studies.

B. Cultural values and expectations determine what science is conducted and accepted.

C. Cultural values and expectations determine how science is conducted and accepted.

D. All cultures conduct scientific research in the same way because science is universal and independent of society and culture.

Explain how society and culture affect or do not affect scientific research. You may provide examples to support your answer.

An adequate view on this component shows that the participant thinks that society and culture determine what and how science is conducted, interpreted or accepted while an inadequate view shows that the participant thinks that science is a search for universal truths and facts and therefore is not affected by society and culture (Liang et al., 2009 as cited in Miller et al., 2010). An intermediate view, in turn, indicates that the participant thinks that society and culture effect either what or how science is conducted, interpreted and accepted. Based on these descriptions, statements 4B and 4C were considered positive as they describe an adequate view while statements 4A and 4D were considered negative as they describe an inadequate view. Table 4.10 and Figure 4.4 depict the results on Component 4 [C4] based on the mean. Table 4.11 depicts the result based on the individual Likert statements of C4.

C4: Social and Cultural Influence on Science			
		Frequency	Percentage
View	Inadequate	19	7.5
	Intermediate	60	23.8
	Adequate	173	68.7
	Total	252	100.0

Table 4.10: Views of all participants based on the mean for C4

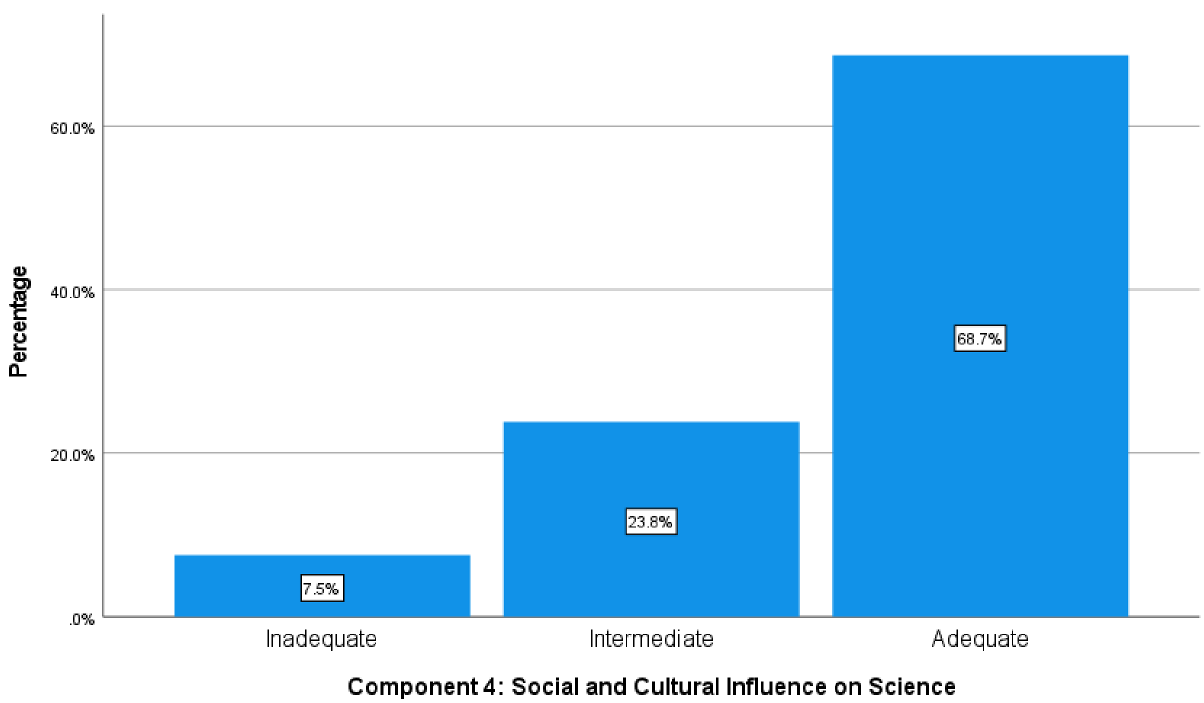

Figure 4.4: A bar graph showing the percentage of views based on the mean for C4

	Inadequate		Intermediate		Adequate		Total	
	N	%	N	%	N	%	N	%
4A: Scientific research is not influenced by society and culture because scientists are trained to conduct pure, unbiased studies.	58	23.0%	22	8.7%	172	68.3%	252	100.0%
4B: Cultural values and expectations determine what science is conducted and accepted.	36	14.3%	32	12.7%	184	73.0%	252	100.0%
4C: Cultural values and expectations determine how science is conducted and accepted.	56	22.5%	31	12.4%	162	65.1%	249	100.0%
4D: All cultures conduct scientific research in the same way because science is universal and independent of society and culture.	46	18.3%	31	12.4%	174	69.3%	251	100.0%

Table 4.11: Views of all participants for each Likert statement on C4

Considering the overall responses based on the mean, 68.7% of participants have adequate views while 23.8% have intermediate and 7.5% have inadequate views. Moreover, the individual Likert sub-scales show that most participants expressed adequate views on all four statements with percentages ranging from 65% to 73%. This shows that Maltese lecturers recognise that society and culture influence what and how science is conducted (4B and 4C) while recognising that science and scientists are not independent of society and culture (4A and 4D).

Once again participants in this study tended to have more adequate views on this component when compared to Maltese science teachers (51.6%) and undergraduates (51.7%) (Pace, 2014; Vella Bondin, 2016). Such a result is corroborated by both the overall mean scores and the individual Likert statements. This finding also corroborates the findings of Bayir et al. (2014) where more than half of participating natural and social scientists recognised the role of society and culture in science. Table 4.12, in turn, combines responses from both open-ended and close-ended questions.

			C4:(Open-ended Response)			Total
			Inadequate	Intermediate	Adequate	
C4:(Close-ended Response)	Inadequate	N	5	8	0	13
		%	3.2%	5.1%	0.0%	8.3%
	Intermediate	N	1	29	4	34
		%	0.6%	18.5%	2.5%	21.7%
	Adequate	N	0	90	20	110
		%	0.0%	57.3%	12.7%	70.1%
Total		N	6	127	24	157
		%	3.8%	80.9%	15.3%	100.0%
Kendall's tau-b = 0.261, p = 0.002						

Table 4.12: Views of all participants on the close-ended and open-ended responses for C4

As one can easily recognize, when considering the participants' written responses, there is a far greater percentage of intermediate views when compared to adequate views. In fact, as seen in Table 4.12, 57.3% of participants that had an adequate view on the close-ended responses expressed an intermediate view in the open-ended responsesince while most participants recognised that society and culture affect what science is conducted, a smaller number of participants recognised that they also affect how science is conducted. For the response to be classified as adequate it had to specify that society and culture influence both what and how science is conducted. Such a result is also evident from the Likert statement results where 73.0% of participants recognised the social and cultural influence on what science is conducted (4B) compared to 65.1% who recognised the social and cultural influence on how science is conducted (4C). A similar result was obtained by Liang et al. (2006). Considering this, however, only 3.8% of participants said that society and culture have no influence on scientific knowledge through the open-ended question. Moreover, the Kendall's Tau-b test also had a *p* value of 0.002 indicating that there is agreement between the responses to the close-ended and open-ended items. Thus, one can conclude that most participants are aware of the social and cultural dimension of science, at least to some extent.

Similarly, all interview participants agreed that social, cultural and political values influence science. The most common examples mentioned in this question were Covid-19 and climate change.Similar to the questionnaire responses, seven of the participants said that social and cultural factors influence the types of studies carried out, with four of these participants directly mentioning issues of funding. However only two participants mentioned that social, cultural or political factors may influence how science is conducted.

Interestingly, another theme which emerged in this question was the issue of conflict which was mentioned by half of the participants. Three participants said that many times science is in collusion with politics while another three mentioned that science can be used to manipulate. The following are examples of such responses:

> *"Smoking was during the 1950's and 1940's, 50's, I don't know if it's in the 60's too promoted by members of the scientific community as a beneficial thing. Now obviously after years of research and after years of studies smoking was related to deaths by cancer right, but obviously the political…some political establishments were influenced by the companies, that is the tobacco companies which were very strong lobbyists and obviously they hindered the process of …they hindered the dissemination and the validation of those types of studies."*

(P6: 4/ 11/2020)

> *"For all I know even the best scientific report on anything, on climate change alright, on ozone depletion, on the coronavirus for all I know, even the best scientific reports can be ditched by policy makers and then they should be the ones shouldering the consequences…as many times there are big conflicts on these things."*

(P7: 7/11/2020)

> *"I think we're returning to days where politics is ...I'll give you the example from America where you know politics and the pandemic are going hand in hand. Where you have, kind of to win more votes at the moment, you know waiting for the results obviously, one administration was downplaying science whilst the other it was you know kind of we should stick more to what the science is saying."*

(P5: 3/11/2020)

4.1.5. Imagination and Creativity in Scientific Investigations

The following items were used to assess the views on this component:

A. Scientists use their imagination and creativity in both the method and the collection of data.

B. Scientists use their imagination and creativity when they analyse and interpret data.

C. Scientists do not use their imagination and creativity because these conflict with their logical reasoning.

D. Scientists do not use their imagination and creativity because these can interfere with objectivity.

Explain whether scientists use OR do not use their imagination and creativity. You may provide examples to support your answer.

An adequate view on this component shows that the participant thinks that scientists use their imagination and creativity throughout the entire process of scientific investigation (Liang et al., 2009 as cited in Miller et al., 2010). Therefore, statements 5A and 5B were considered positive as they describe such a view. An intermediate view shows that the participant thinks that imagination and creativity are only used in some phases of scientific investigation as in designing experiments or problem solving, or simply agrees that they are used but does not elaborate further. An inadequate view shows that the participant thinks that imagination and creativity are not used in science as they conflict with objectivity or logical reasoning (Liang et al., 2009 as cited in Miller et al., 2010). Therefore, statements 5C and 5D were considered negative as the latter view.

Table 4.13 and Figure 4.5 represent the mean results obtained for all participants on Component 5 [C5]. Table 4.14 represents the results of all participants for each Likert statement on C5.

C5: Imagination and Creativity in Scientific Investigation			
		Frequency	Percentage
Valid	Inadequate	27	10.7
	Intermediate	58	23.0
	Adequate	167	66.3
	Total	252	100.0

Table 4.13: Views of all participants based on the mean for C5

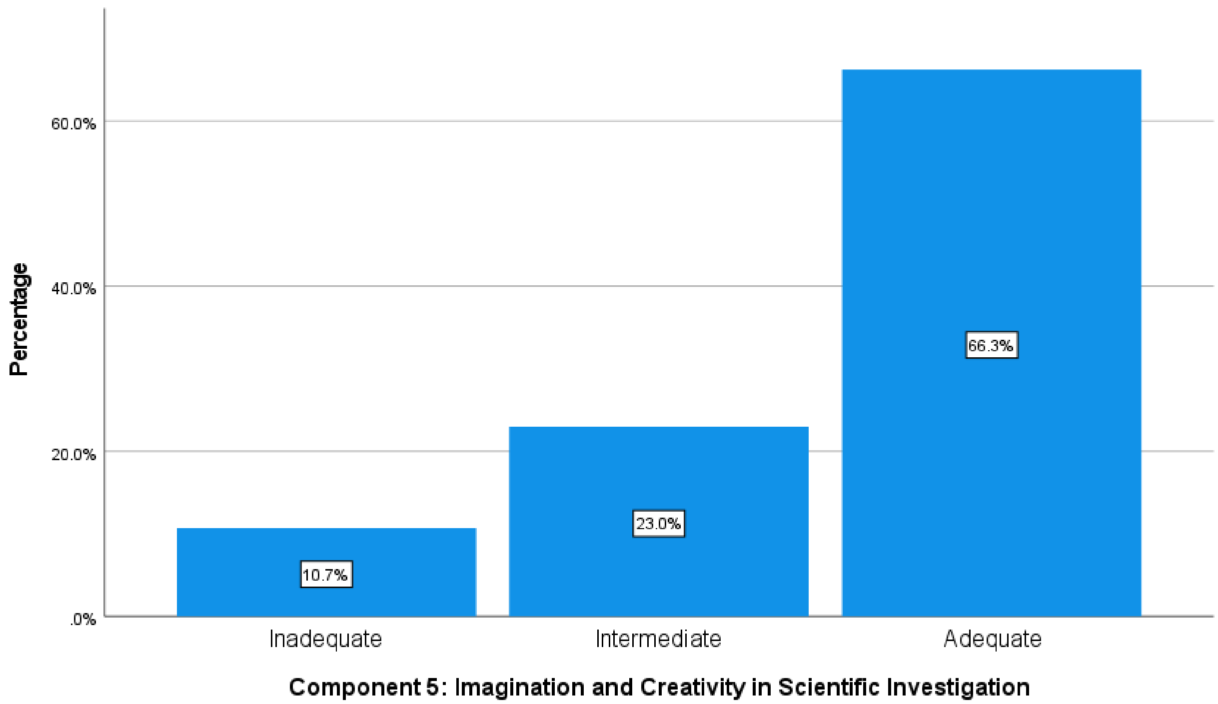

Figure 4.5: A bar graph showing the percentage of views based on the mean for C5

	Inadequate		Intermediate		Adequate		Total	
	N	%	N	%	N	%	N	%
5A: Scientists use their imagination and creativity in both the method and the collection of data.	35	13.9%	26	10.3%	191	75.8%	252	100.0%
5B: Scientists use their imagination and creativity when they analyze and interpret data.	75	29.8%	27	10.7%	150	59.5%	252	100.0%
5C: Scientists do not use their imagination and creativity because these conflict with their logical reasoning.	46	18.5%	24	9.6%	179	71.9%	249	100.0%
5D: Scientists do not use their imagination and creativity because these can interfere with objectivity.	48	19.2%	28	11.2%	174	69.6%	250	100.0%

Table 4.14: Views of all participants for each Likert statement on C5

Table 4.13 and Figure 4.5 show that 66.3% of participants have adequate views on this component, followed by 23.0% with intermediate views and 10.7% with inadequate views. Thus, one can say that the majority of participants appear to have an adequate view on this component. However, when one looks at the individual Likert statements, one can observe that while 75.8% of participants agreed that scientists use their imagination and creativity in both the method and collection of data (5A), a lower 59.5% agreed that imagination and creativity are used during the analysis and interpretation of data (5B). Such results corroborated the findings of Vella Bondin (2016) and Pace (2014). Both studies reported a lower percentage of undergraduate students and secondary science teachers who believed that imagination and creativity are used in the analysis and interpretation of data. Moreover, like the previous component, Maltese lecturers have better views than both teachers and undergraduates (Pace, 2014; Vella Bondin, 2016)since lecturers obtained a higher percentage of adequate views for each individual Likert statement when compared to both populations. Table 4.15 combines the results of the close-ended and open-ended items.

			C5:(Open-ended Response)			Total
			Inadequate	Intermediate	Adequate	
C5:(Close-ended Response)	Inadequate	N	11	4	0	15
		%	7.8%	2.8%	0.0%	10.6%
	Intermediate	N	3	24	0	27
		%	2.1%	17.0%	0.0%	19.1%
	Adequate	N	1	64	34	99
		%	0.7%	45.4%	24.1%	70.2%
Total		N	15	92	34	141
		%	10.6%	65.2%	24.1%	100.0%
Kendall's Tau-b = 0.532, p = < 0.001						

Table 4.15: Views of all participants on the close-ended and open-ended responses for C5

Considering the open responses, most participants at 65.2% had intermediate views while only 24.1% had adequate views. While most participants recognised that imagination and creativity are used in science, their responses were usually short and did not specify when these are used. Similar to the close-ended Likert responses, a number of participants also said that these are used in some phases of science such as the experimental design but not throughout the whole process of scientific investigation. Such responses were considered as intermediate views.

Such a result is similar to the findings of Liang et al. (2009) where Chinese, Turkish and American pre-service teachers also had a higher percentage of intermediate views for the open responses. Moreover, if one considers the Kendall's Tau-b test, a *p* value lower than 0.001 was obtained indicating that there is an agreement between the open-ended and the close-ended responses. Such a result corroborates the findings of Irez (2006) who reported that all fifteen pre-service lecturers recognised that imagination and creativity are used in science, with only three of them saying that these are used throughout the whole process of scientific investigation.

Similar results were obtained through the interviews. Nine out of ten participants agreed that imagination and creativity are used in science with only one participant stating that they should not be used.

> *"I think it should be very minimal, because I think they should stick to facts. It's not like we are speaking about art for example where you can say what you think etc. but these have to be precise."*
>
> (P8: 10/11/2020)

The reason for such a view might be that this participant teaches an area of applied science and has little education and experiencein the traditional science areas. Another six participants who agreed that imagination and creativity are used in science mentioned that they are used when designing the experiment, while only three said that they are used throughout. Interestingly, however, three participants stated that imagination and creativity should be used less when dealing with data. The excerpts below are examples of these responses.

> *"My experience has generated that the more statistics there is the less creativity. Because then you're worried more about the accuracy and the precision and the output than developing an idea and exploring how well it works."*
>
> (P3: 3/11/2020)

> *"I don't think there's an immense amount of creativity involved in actually interpreting the data because then you are bound by certain principles I would say."*
>
> (P4: 3/11/2020)

> *"This means you have to be a little creative from the very start, even in designing the experiment, the techniques used, maybe you won't be when analysing the data, as during data analysis, like we were saying, to decrease that bias which we mentioned earlier, data analysis has to be within a set of parameters that are set before."*
>
> (P10: 11/12/2020)

It is interesting to note that two of these participants are practicing scientists that carry out scientific research in two diverse fields. Such a finding is similar to what was reported by Wong and Hodson (2008) where practicing scientists recognised the role of imagination and creativity throughout the whole scientific process. However, they also said that the nature and extent of creativity and imagination may vary between stages and is usually lower and within tight frameworks during data analysis.

4.1.6. Methodology and Scientific Investigation

This NOS component was tested through the following statements:

A. Scientists use different types of methods to conduct scientific investigations.

B. Scientists follow the same step-by-step scientific method.

C. When scientists use the scientific method correctly, their results are true and accurate.

D. Experiments are not the only means used in the development of scientific knowledge.

Explain whether scientists follow a single, universal scientific method OR use different types of methods. You may provide examples to support your answer.

An adequate view on this component shows that the participant thinks that there is no single, universal, step-by-step scientific method which is followed by all scientists. On the contrary scientists use a variety of methods such as observation, mathematical deduction, library investigation, speculation and experimentation (Liang et al., 2009 as cited in Miller et al., 2010). Thus, statements 6A and 6D were considered positive as they describe such a view. An intermediate view shows that the participant thinks that scientists may use a variety of methods however the results need to be verified through the scientific method or experiments or else the participant simply says that scientists use a variety of methods but does not provide examples or justification. An inadequate view shows that the participant thinks that there is one, single, universal, or step-by-step scientific method (Liang et al., 2009 as cited in Miller et al., 2010). Statements 6B and 6C describe such a view and were therefore considered negative.

Table 4.16 and Figure 4.6 depict the results of all participants on Component 6 [C6] based on the mean. Table 4.17 shows the results of all participants for each individual Likert statement on C6.

C6: Methodology and Scientific Investigation			
		Frequency	Percentage
Valid	Inadequate	4	1.6
	Intermediate	64	25.4
	Adequate	184	73.0
	Total	252	100.0

Table 4.16: Views of all participants based on the mean for C6

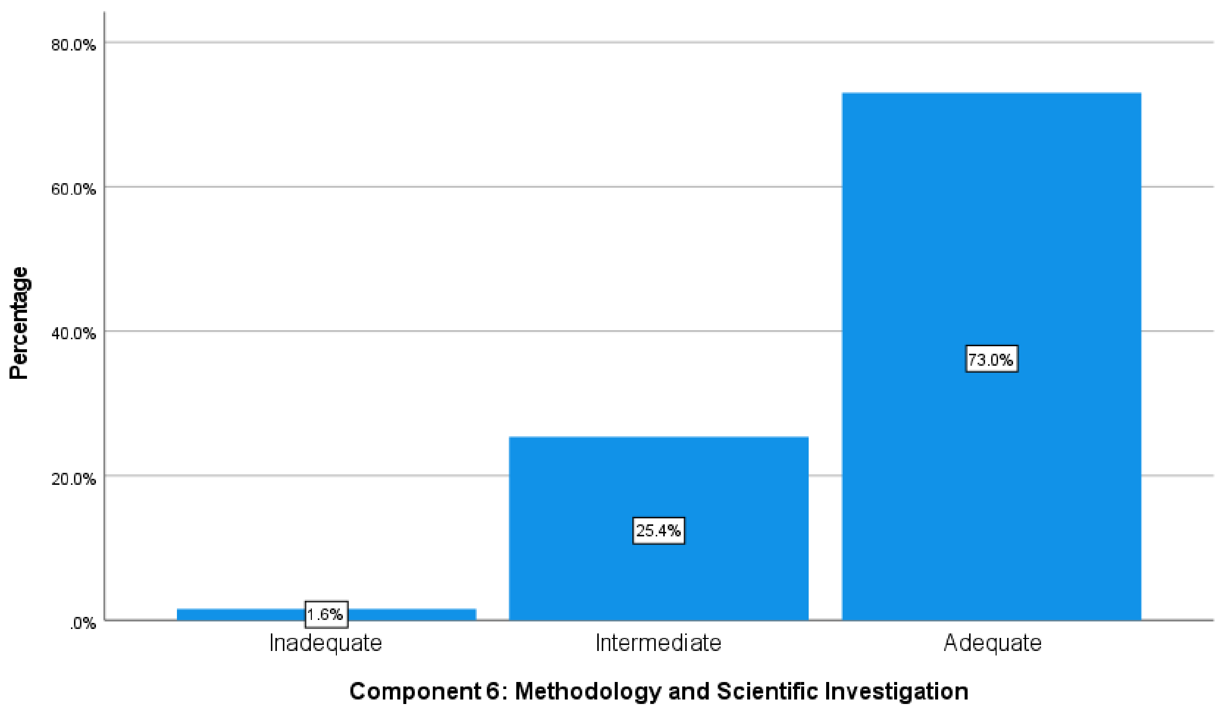

Figure 4.6: A bar graph showing the percentage of views based on the mean for C6

	Inadequate		Intermediate		Adequate		Total	
	N	%	N	%	N	%	N	%
6A: Scientists use different types of methods to conduct scientific investigations.	9	3.6%	9	3.6%	234	92.9%	252	100.0%
6B: Scientists follow the same step-by-step scientific method.	57	22.6%	30	11.9%	165	65.5%	252	100.0%
6C: When scientists use the scientific method correctly, their results are true and accurate.	116	46.0%	51	20.2%	85	33.7%	252	100.0%
6D: Experiments are not the only means used in the development of scientific knowledge.	21	8.3%	28	11.1%	203	80.6%	252	100.0%

Table 4.17: Views of all participants for each Likert statement on C6

The mean values show that 73.0% of participants had adequate views on this component, followed by 25.4%having an intermediate view and 1.6% with an inadequate view. When looking at the individual Likert sub-scales, 92.9% of participants agreed that scientists use different types of methods to conduct scientific investigations (6A) while 80.6% agreed that experiments are not the only means used in the development of scientific knowledge (6D). However,a lower 65.5% of lecturers disagreed that scientists follow the same step-by-step scientific method (6B). This shows that the idea of a universal step-by-step scientific method is still quite popular. Such a view is also highlighted with the fact that 46.0% of participants think that when scientists use the scientific method correctly their results are true and accurate (6C). This corroboratesthe findings by Vella Bondin (2016), Pace (2014) and Liang et al. (2009). All three studies reported that secondary science teachers (Vella Bondin, 2016) and undergraduates (Liang et al., 2009; Pace, 2014) had an overall adequate view on this component, although the individual Likert sub-scales show that the idea of a universal step-by-step scientific method is still present. Moreover, it is interesting to note that like in the case of C3, C4 and C5,Maltese lecturers tended to have better views on this component than Maltese science teachers and undergraduates (Pace, 2014; Vella Bondin, 2016). Table 4.18 combines the results of the open-ended and close-ended items.

			C6:(Open-ended Response)			Total
			Inadequate	Intermediate	Adequate	
C6:(Close-ended Response)	Inadequate	N	4	0	0	4
		%	3.6%	0.0%	0.0%	3.6%
	Intermediate	N	6	5	8	19
		%	5.4%	4.5%	7.1%	17.0%
	Adequate	N	3	43	43	89
		%	2.7%	38.4%	38.4%	79.5%
Total		N	13	48	51	112
		%	11.6%	42.9%	45.5%	100.0%
Kendall's Tau-b = 0.264, p = 0.017						

Table 4.18: Views of all participants on the close-ended and open-ended responses for C6

The results to the open-ended question show that 45.5% of participants exhibited an adequate view followed closely by 42.9% of participants that had an intermediate view and only 11.6% with an inadequate view. Such a relatively high percentage of adequate views,when compared to the open responses of other components, shows that most participants were able to recognise the use of diverse methods in science and mention a few examples of methods. The considerably higher number of intermediate views when compared to the close-ended item (38.4%) may be attributed to the fact that some answers were curt and simply stated that scientists use different methods without presenting examples or justification;such responses were considered as intermediate. Once again, the Kendall's Tau-b test *p* value was lower than 0.05 ($p = 0.017$) indicating an agreement between the different responses.

When looking at the interview results on what drives the development of new scientific knowledge several themes emerged. Seven participants said that the world around us is what drives science, while another four said that observation is an important aspect of science. Interestingly, only one participant mentioned a variety of methods used in science namely theoretical experiments, computer simulations and numerical simulations. Other participants diverged into other areas. A theme which emerged was that there is no pattern in science as it is a combination of things (three participants), it is not a linear process (two participants) and that coincidence plays an important role in discoveries (two participants).

Only three of participating lecturers mentioned aspects of a single scientific method or scientific angle. The excerpts below show examples of such responses:

"Well, there is obviously the scientific method which involves observation, then the formulation of questions, curiosity, first of all, science is driven by curiosity, and curiosity means scientists observe the world around them, ask questions and come up with hypothesis which can be tested."

(P6: 4/11/2020)

"It's the application of the scientific method and the scientific method follows a number of steps, based on observations, hypothesis building, testing the hypothesis by experiment and then as you know well you either refute or confirm the hypothesis."

(P7: 7/11/2020)

Both participants above have a background in science and clearly depict the misconception of a universal step-by-step scientific method. Such a misconception was evident in other studies with scientists who were being trained to become teachers (Peters-Burton, 2016), pre-service science teacher educators (Irez, 2006) anduniversity professors and high school teachers (BouJaoude, 1996). This finding may be attributed to the way science is portrayed in schools especially up to sixth form level and even in some University courses. As Wong and Hodson (2008) explain:

> Despite the resounding message from scientists that context determines method of inquiry, many science teachers continue to instill belief in a common "scientific method"—a myth that is reinforced by the prominence given to "the scientific method" in the introductory chapters of science textbooks.(Wong and Hodson, 2008, p. 125)

The authors recommend that students should be made aware that the experiments done in class are there as 'theatre' to provide evidence for stable and well-established scientific knowledge (Wong and Hodson, 2008).

4.1.7. Overall NOS views of all participants

Considering the views of all participants on the NOS, one notes that Maltese lecturers tend to have adequate views on all NOS components except on C3-Scientific laws vs theories. To confirm this, the combined mean of all six SUSSI components for all participants was worked out. Table 4.19 and Figure 4.7 show these results.

Overall views on the NOS			
		Frequency	Percentage
Valid	Inadequate	4	1.6
	Intermediate	102	40.5
	Adequate	146	57.9
	Total	252	100.0

Table 4.19: Views of all participants based on the mean for the overall NOS

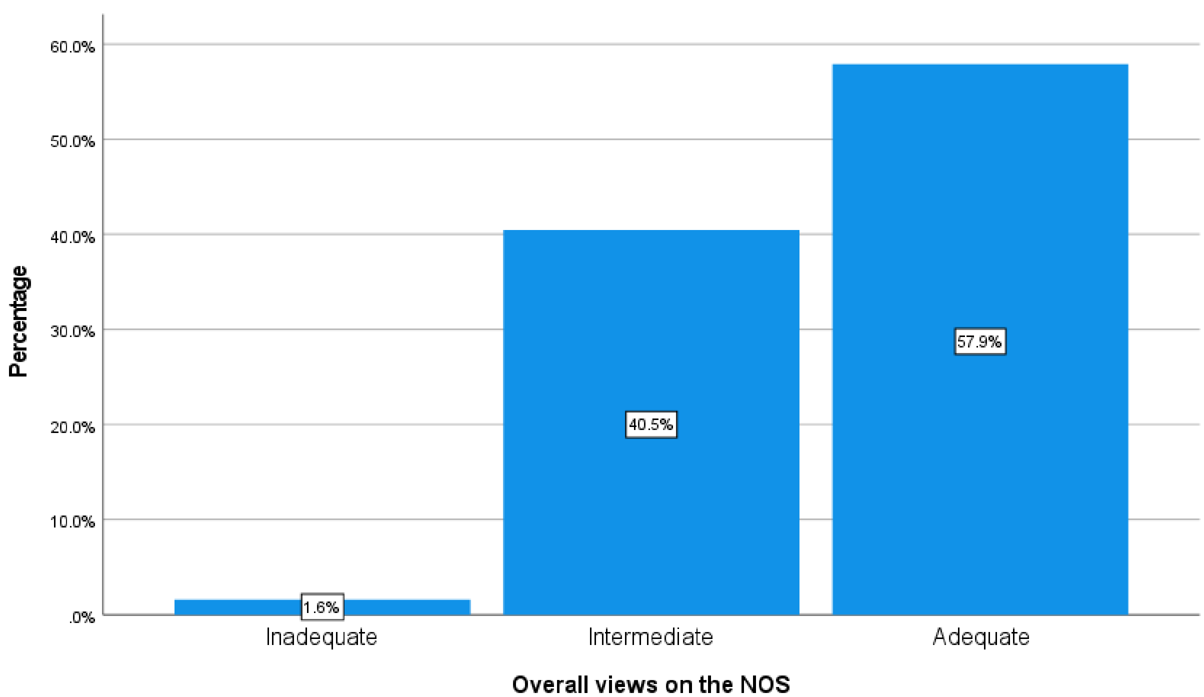

Figure 4.7: A bar graph showing the percentage of views based on the mean for the overall NOS

Table 4.19 shows that 57.9% of participants have adequate overall views, followed by 40.5% who have intermediate views and 1.6% who have inadequate views. Participants exhibited the highest percentage of adequate views on change of scientific theories (87.7%), followed by scientific methodology (73.0%), social and cultural influence on science (68.7%), imagination and creativity in scientific investigations (66.3%) and observations and inferences (62.7%). On the other hand, only 21.0% of participants exhibited adequate views on scientific laws vs theories.

These results vary slightly from those obtained by Vella Bondin (2016) and Pace (2014). Maltese science teachers and Maltese undergraduates exhibited higher percentages of adequate views on observations and inferences and change of scientific theories. This may imply that Maltese lecturers tend to view science as less subjective when compared to teachers and undergraduates. However, lecturers held more adequate views on all other four NOS components indicating that their overall NOS views are more sophisticated. Such a finding is reasonable when considering that lecturers tend to have a higher academic level than both teachers and undergraduates. It is also interesting to note that lecturers had a considerably higher percentage of adequate views on scientific methodology (C6) when compared to both science teachers and undergraduates. This may be because lecturers are more directly involved in research and therefore recognise further the diverse methods used in this area.

In the next section the views of the various subgroups within the population shall be compared.

4.2. Views of participants in various subgroups

In this section the views of participants within various subgroups in the sample population are compared. Initially the distribution of close-ended responses on each of the NOS components was analysed in order to identify the best statistical test suitable for comparison.

Tests for Normality

The Shapiro-Wilk test and the Kolmogorov-Smirnov test were used to check the normality assumption of the score distribution of each component.

- The null hypothesis specifies that the score distribution is normal and is accepted if the *p* value exceeds the 0.05 level of significance.
- The alternative hypothesis specifies that the score distribution is skewed (violates the normality assumption) and is accepted if the *p* value is less than the 0.05 level of significance/ criterion.

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	*p*value	Statistic	df	*p* value
Observations and Inferences	.142	252	.000	.962	252	.000
Change of Scientific Theories	.151	252	.000	.936	252	.000
Scientific Laws vs Theories	.136	252	.000	.964	252	.000
Social and Cultural Influence on Science	.167	252	.000	.952	252	.000
Imagination and Creativity in Scientific Investigation	.175	252	.000	.944	252	.000
Methodology and Scientific Investigation	.124	252	.000	.975	252	.000

Table 4.20: Tests for Normality

The above table shows that all six score distributions violate the normality assumption since all *p*values are less than the 0.05 level of significance. For this reason, a non-parametric test will be used.

The Kruskal-Wallis test was chosen to compare the mean component scores of the close-ended responses between various independent subgroups such as gender, lecturing experience, age group, etc. These mean rating scores range from 1 to 5 where a value close to 1 indicates a very inadequate view and a score close to 5 indicates a very adequate view. So, the higher the mean score the more adequate is the view.

- The null hypothesis specifies that the mean scores vary marginally between the groups and is accepted if the *p* value exceeds the 0.05 level of significance.
- The alternative hypothesis specifies that the mean scores vary significantly between the groups and is accepted if the *p* value is less than the 0.05 criterion.

These null and alternative hypotheses will be used throughout for the Kruskal-Wallis test. If significant differences are found in demographic variables with more than two subgroups, post hoc analysis will be used to make pairwise comparisons and identify where these differences are. Given that the open responses are qualitative in nature and the number of responses within subgroups was small, excerpts of these together with interview excerpts shall be used to support the data from the close-ended responses.

4.2.1. Variation by Gender

Table 4.21 compares the results of male and female participants on each of the six SUSSI close-ended items while Figure 4.8 portrays these results graphically.

		N	Mean	Std. Deviation	*p* value
C1: Observations and Inferences	Male	151	3.54	.776	0.534
	Female	101	3.60	.783	
C2: Change of Scientific Theories	Male	151	4.00	.652	0.206
	Female	101	3.94	.599	
C3: Scientific Laws vs Theories	Male	151	2.96	.633	0.005
	Female	101	2.73	.568	
C4: Social and Cultural Influence on Science	Male	151	3.61	.795	0.384
	Female	101	3.68	.855	
C5: Imagination and Creativity in Scientific Investigation	Male	151	3.69	.840	0.207
	Female	101	3.52	.966	
C6: Methodology and Scientific Investigation	Male	151	3.65	.569	0.922
	Female	101	3.66	.581	

Table 4.21: Kruskal-Wallis test for the close-ended responses by gender

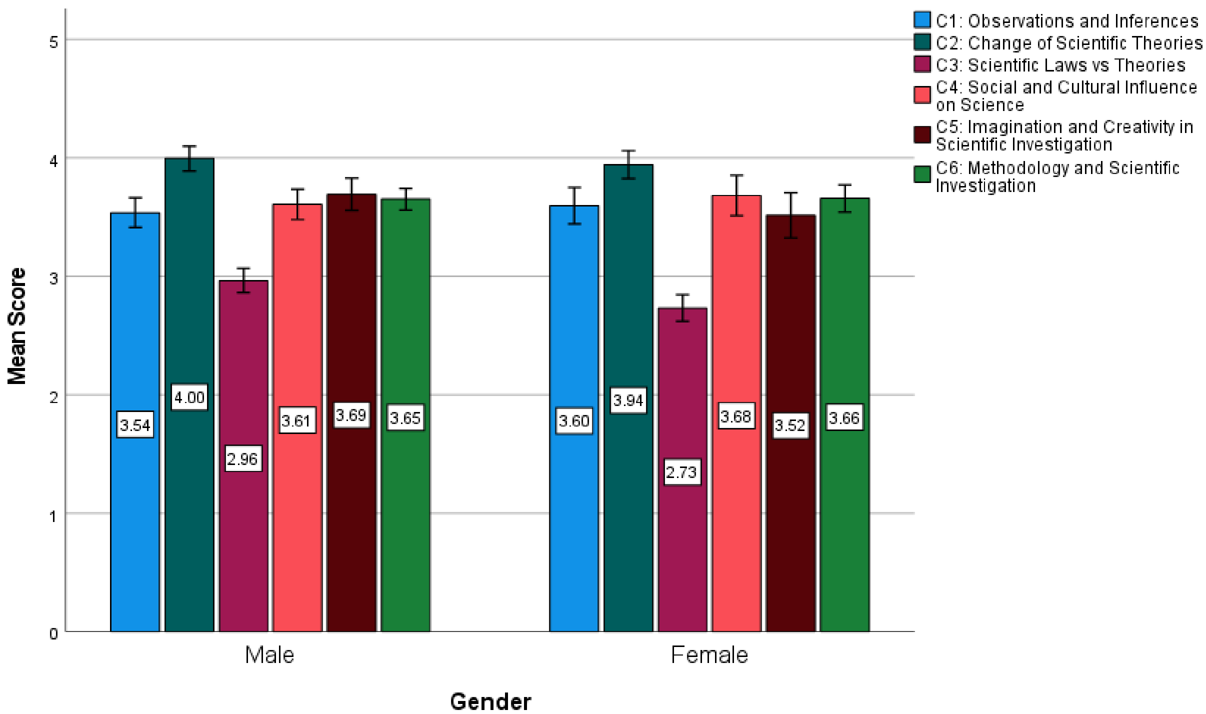

Figure 4.8: An error bar graph showing the mean score on all NOS components by gender

As seen in Table 4.21, there are more participating males than females in this study. This is not surprising when considering that most lecturers came from science or science-related areas which are usually male-dominated (Brotman and Moore, 2008). Analysing the mean scores obtained, one can notice that males and females have similar views on components 1, 2, 4, 5, and 6. In fact all means on these components are above 3. This indicates no gender discrepancy and both gender groups have a rather adequate view on each of these components.

On the other hand, both males and females scored less than 3 on scientific laws vs theories (C3). Moreover, the mean score of females is significantly lower than that of males with a *p* value of 0.005. This implies that both males and females have a rather inadequate view for this component; the inadequacy is more evident in females than in males.

The error bar graph displays the 95% confidence interval of the actual mean score of each component for each group. When two confidence intervals overlap considerably, they indicate that their mean scores are similar. On the other hand, when two confidence intervals are disjointed or overlap slightly, their mean scores differ significantly. As one can see, the confidence intervals for males and females on scientific laws vs theories only overlap slightly showing the significant difference that is also indicated by the*p* value.

Such a statistical difference however couldn't be corroborated by open-ended and interview responses as most participants tended to express inadequate views on laws and theories irrelevant of gender. Similarly, both Karaman (2017) and Pace (2014) reported no gender differences on any of the NOS components of the SUSSI questionnaire.

4.2.2. Variation by Age Group and Lecturing Experience

The Kruskal-Wallis test was worked out to compare the views of participants by age group and lecturing experience for the close-ended item on all six SUSSI components. However, these subgroups yielded no statistical differences in any of the components. The tables of results and graphs for these components can be found in Appendix F.

4.2.3. Area of specialisation

The views of participants were also compared by area of specialisation. In both the questionnaire and the interview, participants were asked to choose whether their closest area is a pure science, an applied science or a humanities area. Lecturers might have passed through various pathways to arrive to their current lecturing position. For example, a lecturer in Maths and Physics might have an engineering degree, while a lecturer in applied science might have a B.Sc. in Biology and Chemistry. Considering that no classification fits all these various pathways it was thought that it is best to leave it up to the lecturer to decide which is his/ her main area of specialisation. Considering this, the subjective nature of such a classification might limit the application of such findings.

Table 4.25 and Figure 4.10 depict the results obtained for each of the six SUSSI components based on the close-ended questions. Tables 4.26 and 4.27 show the post hoc analysis for two of the components where a statistically significant difference was found. These analyses show pairwise comparisons of the three groups.

		N	Mean	Std. Deviation	*p* value
C1: Observations and Inferences	Pure Science	88	3.57	.826	0.906
	Applied Science	107	3.54	.759	
	Humanities	55	3.59	.744	
C2: Change of Scientific Theories	Pure Science	88	4.06	.581	0.008
	Applied Science	107	3.83	.698	
	Humanities	55	4.12	.516	
C3: Scientific Laws vs Theories	Pure Science	88	2.97	.651	0.139
	Applied Science	107	2.80	.590	
	Humanities	55	2.85	.602	
C4: Social and Cultural Influence on Science	Pure Science	88	3.64	.901	0.481
	Applied Science	107	3.62	.725	
	Humanities	55	3.70	.869	
C5: Imagination and Creativity in Scientific Investigation	Pure Science	88	3.85	.875	0.008
	Applied Science	107	3.48	.863	
	Humanities	55	3.53	.943	
C6: Methodology and Scientific Investigation	Pure Science	88	3.68	.620	0.424
	Applied Science	107	3.67	.563	
	Humanities	55	3.58	.523	

Table 4.22: Kruskal-Wallis test for the close-ended responses by area of specialisation

	Test Statistic	Std. Error	Std. Test Statistic	*p* value
Applied Science-Pure Science	24.449	10.294	2.375	.018
Applied Science-Humanities	-32.759	11.868	-2.760	.006
Pure Science-Humanities	-8.309	12.295	-.676	.499

Table 4.23: Pairwise Comparison by area of specialisation for C2: Change of Scientific Theories

	Test Statistic	Std. Error	Std. Test Statistic	*p* value
Applied Science-Humanities	-7.029	11.873	-.592	.554
Applied Science-Pure Science	31.251	10.298	3.035	.002
Humanities-Pure Science	24.223	12.300	1.969	.049

Table 4.24: Pairwise Comparison by area of specialisation for C5: Imagination and Creativity in Scientific Investigation

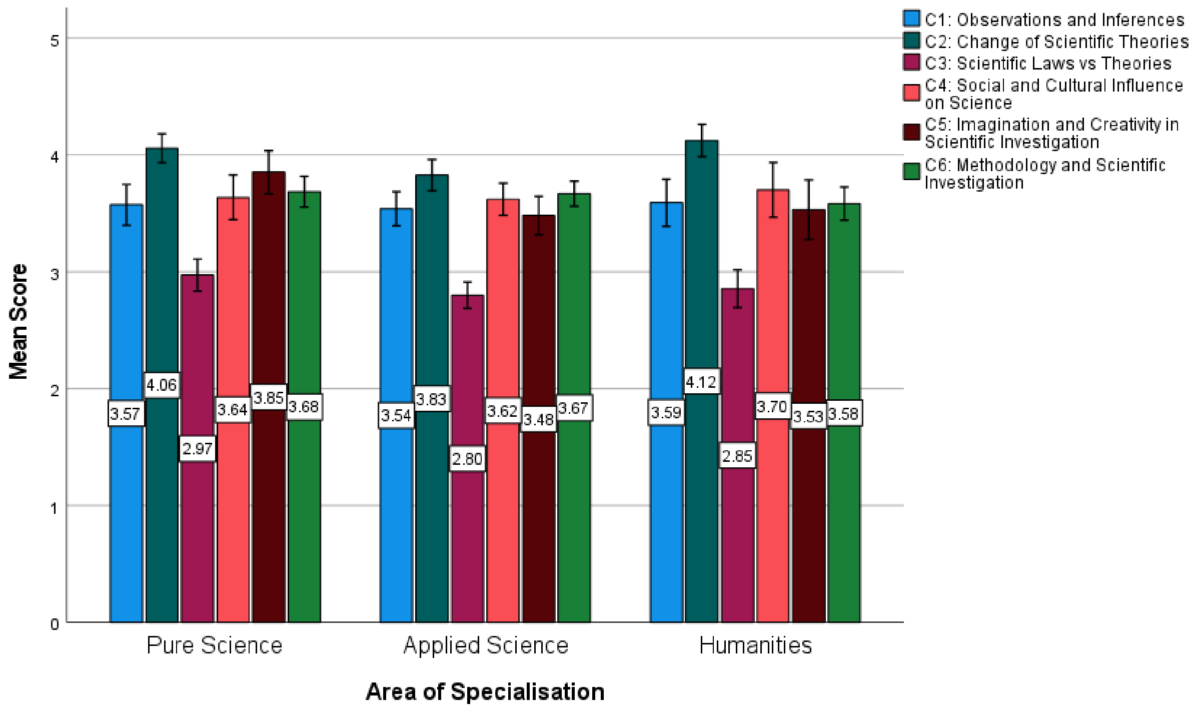

Figure 4.9: An error bar graph showing the mean score on all NOS components by area of specialisation

The mean values show that applied science lecturers tended to have the lowest mean value on most components except C6: Methodology and Scientific Investigation. Such differences were statistically insignificant on components 1, 3, 4 and 6. However, a statistically significant difference between subgroups was found on the change of scientific theories (C2) and the use of imagination and creativity in scientific investigation (C5).

Considering C2: Change of Scientific Theories, both pure science and humanities lecturers obtained a mean value above 4 while applied science lecturers had a mean value of 3.83. Post hoc analysis showed that this difference was statistically significant between applied science and pure science lecturers ($p = 0.018$) and applied science and humanities lecturers ($p = 0.006$). The difference between pure science and humanities lecturers on change of scientific theories was not significant. Thus, pure science and humanities lecturers tend to recognise the tentative nature of scientific theories more than applied science lecturers. The following excerpts from open responses and interviews describe some of these views.

“There have been examples in the past where new interpretation of facts resulted in a change in the theories. No interpretation of reality is in actual fact absolute.”

(Open response 13-Humanities)

“I think there are… some theories which are fixed. So, I believe that some… you need to learn specific theories by heart sort of because they would remain as it is. But if we’re speaking for example about my area in computing although some theories are fixed, others are improved.”

(P8: 10/11/2020-Applied Science)

“Theories change. Because if you take atomic theory. This theory of how the atom looks like and it would kind of…the observations would kind of show that the present theory does not hold.”

(P1: 18/08/2020-Pure Science)

The findings on the use of imagination and creativity in science were similar. One notes that applied science lecturers had the lowest mean value (3.48) followed by humanities lecturers (3.58) and pure science lecturers (3.85). Once again, this shows that pure science and humanities lecturers recognise the imaginative and creative aspect of NOS more than applied science lecturers. Post hoc analysis however yielded that these differences are only statistically significant when comparing pure science and applied science ($p = 0.002$) and pure science and humanities lecturers ($p = 0.049$).

Such a result can also be confirmed with qualitative data from both the open-ended responses and interviews. The excerpts below show examples of responses from lecturers in different areas on imagination and creativity in science.

“Imagination and creativity can be used in collecting data unless these interfere with objectivity. In analysing data, scientists have to stick to objectivity as much as possible.”

(Open response 145-Applied Science)

“In order to devise the best methods and make sense of what is observed, imagination and creativity might help to think outside the box and make connections to things which have not been previously linked to that particular study.”

(Open response 51-Pure Science)

"Imagination and creativity precede, accompany and exceed the work of scientists. They keep our theories and laws flexible and renewable."

(Open response 182-Humanities)

One can say that applied science lecturers generally tend to have more naïve views on the NOS especially when looking at the imaginative and creative aspects of NOS as well as the tentative nature of scientific theories. Such a finding compares with that of another study where pre-servicelecturers with an engineering background held naïve views on the NOS when compared to those with a science or education background (Irez, 2006). One tends to agree with the authors that lecturers in the applied sciences would usually be more concerned about the pragmatic application of science rather than the epistemological nature of the knowledge. Thus, lack of prior reflection on the NOS might have yielded such a difference (Irez, 2006).

4.2.4. Closest Traditional Science Area

Participants who are lecturers in science or science-related areas were asked to identify their closest traditional science area, that is either Physics, Biology or Chemistry. The participants' views were then compared. Table 4.28 and Figure 4.11 show these results for all six SUSSI components. Tables 4.29 and 4.30 in turn show post hoc analysis on two of the components where a statistically significant difference was found.

		N	Mean	Std. Deviation	*p* value
C1: Observations and Inferences	Biology	68	3.69	.682	0.178
	Chemistry	32	3.52	.814	
	Physics	84	3.46	.825	
C2: Change of Scientific Theories	Biology	68	4.07	.543	0.004
	Chemistry	32	4.20	.512	
	Physics	84	3.75	.757	
C3: Scientific Laws vs Theories	Biology	68	2.90	.592	0.115
	Chemistry	32	3.04	.645	
	Physics	84	2.81	.652	
C4: Social and Cultural Influence on Science	Biology	68	3.88	.641	0.012
	Chemistry	32	3.59	.935	
	Physics	84	3.48	.830	
C5: Imagination and Creativity in Scientific Investigation	Biology	68	3.59	.811	0.083
	Chemistry	32	3.98	.798	
	Physics	84	3.62	.946	
C6: Methodology and Scientific Investigation	Biology	68	3.59	.566	0.408
	Chemistry	32	3.67	.802	
	Physics	84	3.72	.512	

Table 4.25: Kruskal-Wallis test for the close-ended responses by closest, traditional science area

	Test Statistic	Std. Error	Std. Test Statistic	*p* value
Physics-Biology	20.972	8.594	2.440	.015
Physics-Chemistry	32.307	10.945	2.952	.003
Biology-Chemistry	-11.335	11.294	-1.004	.316

Table 4.26: Pairwise Comparison by closest, traditional science area for C2: Change of Scientific Theories

	Test Statistic	Std. Error	Std. Test Statistic	*p* value
Physics-Chemistry	9.879	10.962	.901	.367
Physics-Biology	25.550	8.608	2.968	.003
Chemistry-Biology	15.671	11.312	1.385	.166

Table 4.27: Pairwise Comparison by closest, traditional science area for C4: Social and Cultural Influence on Science

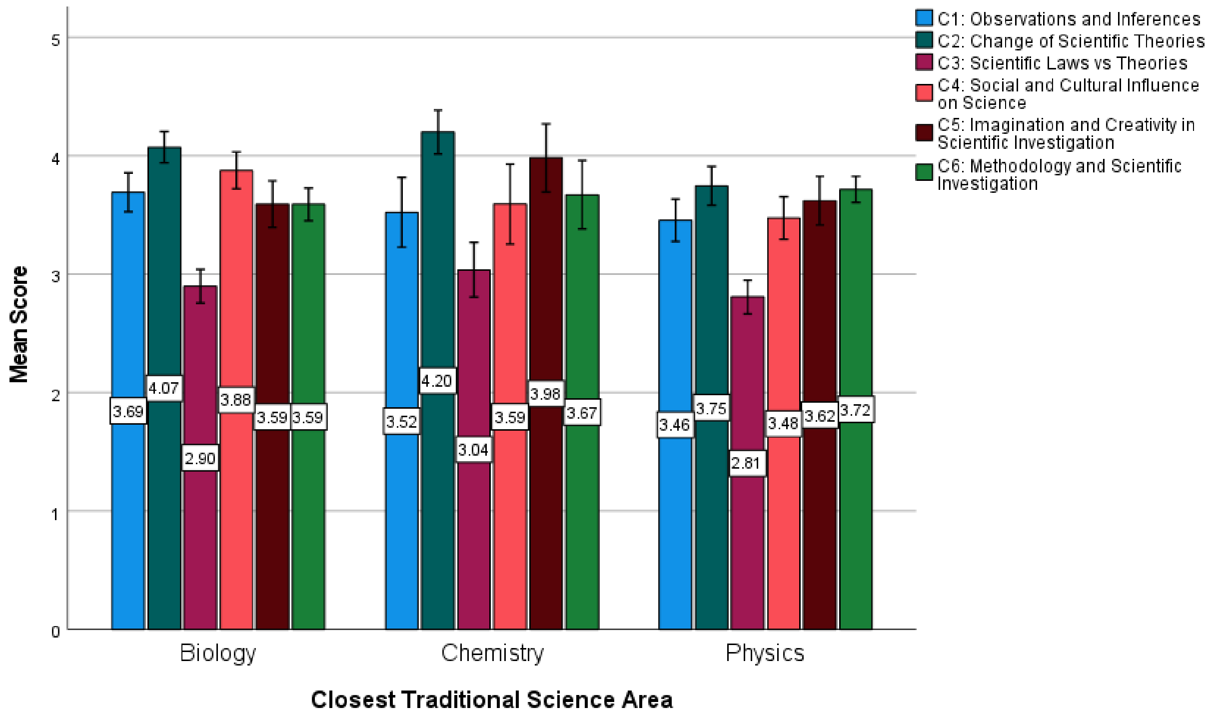

Figure 4.10: An error bar graph showing the mean score on all NOS components by closest, traditional science area

Figure 4.11 and Table 4.28 indicate that lecturers whose closest traditional science area is Physics tended to have the least adequate views on components 1, 2, 3 and 4. However, they exhibited highly adequate views on scientific methodology (C6) and scored more than lecturers whose closest traditional area is Biology in imagination and creativity in science (C5). Differences between the three groups were only significant on change of scientific theories (C2) and the social and cultural aspect of science (C4), where a *p* value lower than 0.05 was obtained.

Regarding the views on change of scientific theories, Chemistry lecturers obtained a mean score of 4.20, followed by Biology lecturers with a mean score of 4.07 and Physics lecturers with a mean score of 3.75. Post hoc analysis yielded significant differences between Physics and Chemistry lecturers (*p* = 0.003) and Physics and Biology lecturers (*p* = 0.015) showing that Physics lecturers tend to have more naïve views on the tentativeness of scientific theories. Such a finding corroborates the findings by Vella Bondin (2016) who said that Maltese, Physics, secondary teachers tended to think that scientific theories based on accurate experiments will not change. Lecturers' interview responses on the question on scientific theories, with Physics as closest traditional area, tended to diverge into the distinction between laws and theories. They all implied that there are some theories or laws that will not change while others will. The following are excerpts of such responses.

> *"For example, if you take Newton's laws of motion they've now been tried and tested, so to speak, you know if we've used them, done experiments, we've used them in practice and the numbers hold, you know and so they are laws."*
>
> (P1: 18/08/2020-Physics)

> *"I think it depends on the evidence we have at hand and again it goes back to the stage of how long the theory has been there and if we're going to distinguish between a theory and a law."*
>
> (P9: 14/11/2020-Physics)

Such a finding may imply that the mathematical basis of Physics coupled with the importance attributed to scientific laws in some areas of Physics may contribute to a more absolutist view on science, making it more 'crystallised' when compared to the other natural sciences.

In turn, when looking at the social and cultural aspect of science (C4), Biology lecturers had the highest mean value (3.88), followed by Chemistry lecturers (3.59) and Physics lecturers (3.48) respectively. As seen in Table 4.30 the difference between Physics and Biology lecturers was found to be statistically significant with a *p* value of 0.003.

Once again, this finding corroborates what was obtained by Vella Bondin (2016) who reports that Maltese, Biology teachers scored the highest on all four SUSSI statements of this component, while Physics teachers scored the lowest. Similarly, Shi and Wang (2017) report low scores on the social and cultural influence on science for undergraduate Physics majors. Schwartz and Lederman (2008) also report similar findings when comparing the views of scientists from different areas. In view of this, one tends to agree with Vella Bondin (2016) that once again the mathematical basis of Physics may be a contributing factor to the idea that such knowledge is not influenced by society and culture.

While participant interviewees whose main traditional area is Physics regarded mathematics as a contributing factor to certainty, at least they recognised the social and cultural aspect of science to some extent. However, the examples they brought up tended to be from other areas. The following are excerpts of their responses:

> *"Sometimes the influence could be at multiple levels, for example, take the situation now, there is definitely a lot of political pressure for scientists to focus on covid related experiments. And therefore, even if there are other diseases that you know maybe are more widespread or you know, have been with us for longer, they are put aside because right now the focus is on covid."*
>
> (P1: 18/08/2020-Physics)

> *"If we look at the amount of money invested into for example when mobile phones first came out, the amount of money invested in that area was significantly greater when compared to the money invested to I don't know any other subject but because there was the risk to the human being obviously money is funded in that direction and therefore politics and all this influence the way science would elaborate."*
>
> (P9: 14/11/2020-Physics)

4.2.5. Highest qualification

Finally, the views of participants were compared by highest qualification, that is, whether they had a Bachelors, a Masters or a PhD level of education. Table 4.31 and Figure 4.10 show these results on all six SUSSI components. Table 4.32 depicts pairwise comparisons on C2as a statistically significant difference was found on this component.

		N	Mean	Std. Deviation	*p* value
C1: Observations and Inferences	Bachelors	34	3.43	.782	0.498
	Masters	106	3.61	.725	
	PhD	111	3.57	.816	
C2: Change of Scientific Theories	Bachelors	34	3.72	.863	0.010
	Masters	106	3.92	.609	
	PhD	111	4.11	.533	
C3: Scientific Laws vs Theories	Bachelors	34	2.76	.724	0.181
	Masters	106	2.88	.534	
	PhD	111	2.90	.659	
C4: Social and Cultural Influence on Science	Bachelors	34	3.50	.778	0.231
	Masters	106	3.62	.796	
	PhD	111	3.70	.856	
C5: Imagination and Creativity in Scientific Investigation	Bachelors	34	3.56	.950	0.795
	Masters	106	3.59	.943	
	PhD	111	3.68	.834	
C6: Methodology and Scientific Investigation	Bachelors	34	3.65	.457	0.071
	Masters	106	3.56	.566	
	PhD	111	3.75	.602	

Table 4.28: Kruskal-Wallis test for the close-ended responses by highest qualification

	Test Statistic	Std. Error	Std. Test Statistic	*p* value
Bachelors-Masters	-10.598	14.156	-.749	.454
Bachelors-PhD	-34.739	14.078	-2.468	.014
Masters-PhD	-24.141	9.754	-2.475	.013

Table 4.29: Pairwise Comparison by highest qualification for C2: Change of Scientific Theories

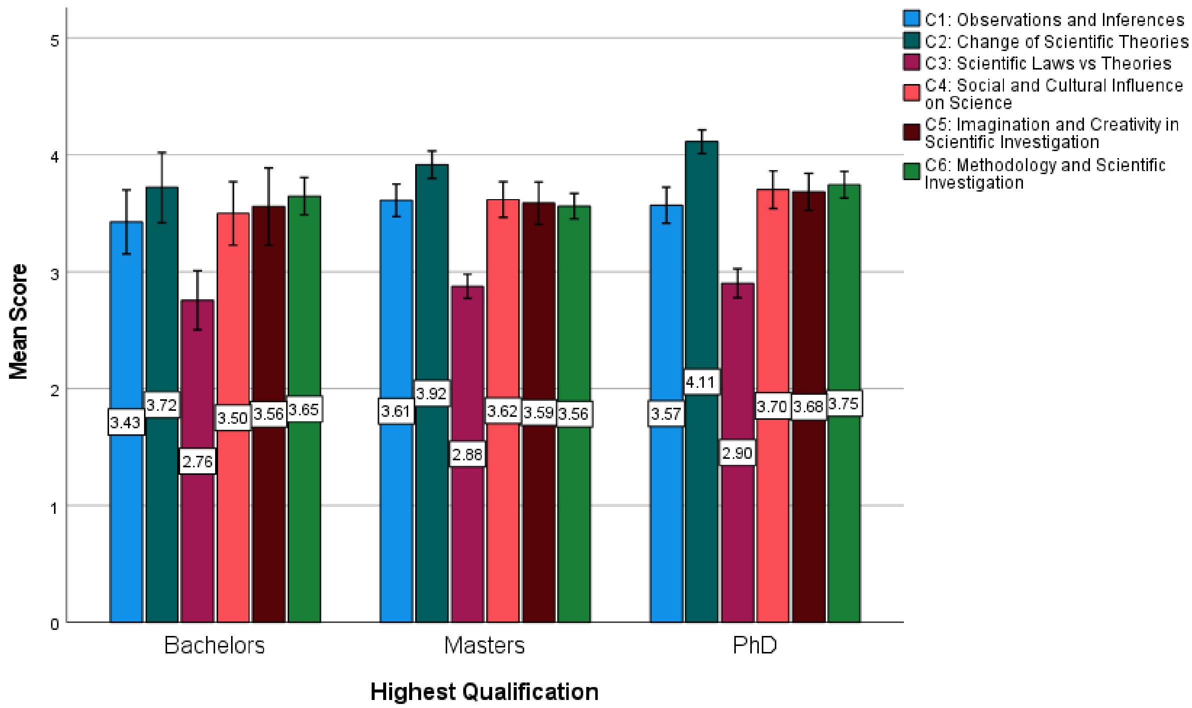

Figure 4.11: An error bar graph showing the mean score on all NOS components by highest qualification

Considering the mean values by highest qualifications, one can notice that views tend to improve on four NOS components, namely C2, C3, C4 and C5, as qualifications increase although these differences were only statistically significant for change of scientific theories (C2). Here participants with a PhD obtained a mean value of 4.11, followed by participants with a Masters, with a mean value of 3.92 and a Bachelors at a mean of 3.72. Pairwise comparisons yielded statistically significant differences between PhD and Masters ($p = 0.013$) and PhD and Bachelors ($p = 0.014$).

Such a finding is interesting when considering that both Pace (2014) and Karaman (2017) report minimal differences by year of study or grade level in undergraduate students. This may show that university courses have little effect on students' NOS views. However, in a paper about PhD science courses, Bosch (2018) argued that such courses should include a reflection on the bigger picture of science, the limits of scientific knowledge and scientific advancements from a moral point of view. Such aspects are related to the NOS.

Thus, most interviewees,whatever their highest qualification, tended to have adequate views on the tentative nature of scientific theories, although interestingly, two of the interviewees made direct mention to their PhD research and its contribution to some of their views on the fallible nature of scientific knowledge.

Both participants said that throughout their PhD in the natural sciences they were asked to look at their research from the artistic or, rather, the philosophical aspect, and hence recognise the limitations of their findings or how these are subject to interpretation. The following are excerpts of their responses.

> *"Mmmm yes. As in having gone, recently gone, through my viva yes surely. As in not drastically different conclusions but different conclusions yes. That is in fact if I may …maybe where the…if you want to call it artistic, the artistic touch comes into science because I might look at a data and say ok there are three lines for example and these three lines depict this…but you might give it a completely different flavour by even your experience in the area might allow you to elaborate further on the interpretation of those three lines."*
>
> (P9: 14/11/2020-PhD)

> *"But the idea that your study is not going to answer all the questions. And that there still might be philosophical aspects that still need to be considered or contemplated. Or subject to another study in the future. Which goes back to kind of it's just a Doctor of Philosophy or a PhD what it's all about is…you might be doing research in the natural sciences but there's a bit of philosophy or art to it in order to appreciate what you don't quite understand yet. They often say the best research studies result in…for every question answer you get two more questions."*
>
> (P2: 2/11/2020-PhD)

Therefore, this may imply that higher qualifications, especially at PhD level, make one reflect further on the nature of research and the knowledge being produced and this can ultimately positively contribute to better NOS views on the tentative aspect of NOS.

4.2.6: Overall findings on the NOS within the various subgroups

When comparing the NOS views by the various demographic variables, significant differences were found on a few of the components when comparing views by gender, area of specialisation, closest, traditional science area and highest qualification. Lecturing experience and age group yielded no significant differences on any of the components.

The gender variable yielded no significant difference on most components. Such a finding corroborates what was obtained by both Karaman (2017) and Pace (2014). The only significant difference found was on scientific laws vs theories (C3), where males exhibited better views than their female counterparts. However, such a finding was not corroborated by interviews or open-ended responses where participants tended to express inadequate views irrelevant of gender. In fact, considering other studies on differences in NOS views by gender, results appear to be ambivalent. Similar to this study, Tsai and Liu (2011) report better views for males on the tentative aspect of NOS. On the other hand, Cauchi (1999) and Mifsud (1997) report better views in females on the subjective NOS; they argue that males tend to have more objective views than females. Considering this, coupled with the fact that such a result was not corroborated by qualitative data, such a difference may not be as conclusive and further studies may be needed in the area.

The most noticeable differences in this study occurred when comparing NOS views by area of specialisation. In fact, two of the components, namely change of scientific theories (C2) and imagination and creativity in scientific investigation (C5) yielded a statistically significant difference. When looking at the tentativeness of scientific theories, pure science and humanities lecturers appeared to have similar views while applied science lecturers manifested more naïve views. The similarity of views between pure science and humanities lecturers corroborates what Bayir et al. (2014) report in a study carried out with natural and social scientists. The authors concluded that social and natural scientists held similar views on the tentativeness of the NOS. Irez (2006) reports a difference on the tentative NOS in pre-service lecturers with various academic backgrounds including engineering, science and education. Lecturers with a background in engineering, which can be considered an applied science, appeared to have more naïve views than their science and education counterparts.

Regarding the use of imagination and creativity in science, pure science lecturers held the most informed views, followed by humanities and applied science lecturers respectively. However here the difference appeared to be statistically significant between pure science lecturers and the other two groups. Bayir et al. (2014) report a similar finding when comparing natural and social scientists' views on imagination and creativity in science. While both social and natural scientists recognised the role of creativity in science, a far lower percentage of social scientists recognised the role of imagination in science. Irez (2006) also reported better views in lecturers with a science and education background when compared to those with an engineering background. Such naïve views in lecturers with an applied science background can be attributed to a lack of prior reflection on the NOS (Irez, 2006). This may be because applied science lecturers tend to be more focused on the practical application of science rather than the epistemological characteristics of the knowledge produced.

Another demographic variablethat was investigated is the lecturers' closest, traditional science area. Lecturers whose closest traditional science area is Physics exhibited more naïve views on four NOS components with these differences being statistically significant on change of scientific theories (C2) and the social and cultural aspects of science (C4). Such a finding corroborates other studies (Schwartz and Lederman, 2008; Shi and Wang, 2017; Vella Bondin, 2016). Shi and Wang (2017) concluded that Maths and Physics majors exhibited inadequate views on the subjective NOS and the social and cultural dimension of NOS. Schwartz and Lederman (2008) in turn compared the views of 24 different scientists specialising in various areas. They also reported that theoretical physicists had more naïve views on the social and cultural dimension of science when compared to scientists from other areas. Considering this, one tends to agree with Vella Bondin (2016) who reported similar findings in Maltese Physics teachers and stated that the mathematical basis of Physics may negatively influence NOS views as it makes one perceive science as absolute and hence not effected by social and cultural factors.

Another significant difference was found when comparing NOS views by highest qualification. NOS views tended to improve by higher qualifications on four of the NOS components namely change of scientific theories (C2), scientific laws vs theories (C3), the social and cultural aspect of science (C4) and imagination and creativity in science (C5). A statistically significant difference was found on change of scientific theories (C2) where participants with a PhD appeared to recognise the tentative nature of scientific theories more than participants with lower qualifications. A PhD programme requires the submission of an original thesis on the specific area, which will contribute to knowledge (Haidar, 2020). Bosch (2018) argues that science PhD courses should make students reflect on the bigger picture and "the limits of science, and where science's ability to do something competes with what scientists should do from a moral point of view" (Bosch, 2018, p. 277) that are aspects that are directly linked to the NOS. Thus, one can argue that such reflections coupled with the fact that higher qualifications will yield more research experience, generally enables academics with such qualifications to develop better NOS views.

5. Conclusion

5.1. Summary of Findings

The research questions investigated in this study were:

What are the NOS views of Maltese post-secondary lecturers?

- Is there a difference between pure science lecturers, applied science lecturers and humanities lecturers?
- Considering lecturers in the natural sciences and science-related courses, are there differences according to whether their background is biology, chemistry or physics?
- Is there a difference by years of experience in the field?
- Is there a difference by age bracket?
- Is there a difference depending on qualifications?
- Is there a difference between males and females?

Findings show that most Maltese lecturers have intermediate to adequate views of the NOS on all six SUSSI components. Similar to other studies (Bayir et al., 2014; Irez, 2006; Karaman, 2017; Liang et al., 2008; Vella Bondin, 2016; Wong and Hodson, 2008) inadequate views were mostly common on the distinction between laws and theories. Intermediate to adequate views were observed on all other five NOS components. Considering the close-ended responses, at least 60% of participants exhibited adequate views on all five NOS components. When looking at the open responses a higher number of participants exhibited intermediate rather than adequate views. However, frequently, this was attributable to incomplete, short answers or a stringent rubric when it comes to classifying responses (Liang et al., 2006). Interview responses mostly tended to support questionnaire findings as most participants expressed similar views to those found through the questionnaire.

When looking at findings within the various subgroups, a high uniformity was observed on most components. In fact, age group and lecturing experience yielded no significant differences on any NOS component. Only gender yielded a significant difference on the distinction between laws and theories, with males exhibiting better views than females. However, such a result was not corroborated by the open responses or the interview findings.

Comparison by area of specialisation showed that lecturers who teach in the applied sciences exhibited more naïve views than pure science and/or humanities lecturers when looking at five aspects of the NOS. However, such differences were only statistically significant on the change of scientific theories and the use of imagination and creativity in science. Humanities and pure science lecturers had adequate views on change of scientific theories when compared to applied science lecturers. When looking at the use of imagination and creativity, pure science lecturers exhibited better views than both applied science and humanities lecturers with these differences being statistically significant.

In turn, comparison by closest, traditional science area showed that lecturers whose closest area is Physics held inadequate views on four NOS components, namely observations and inferences, change of scientific theories, scientific laws vs theories and the social and cultural influence on science, when compared to Biology and Chemistry counterparts. These differences were statistically significant on two of the components namely change of scientific theories and the social and cultural influence on science. Such naïve views on the NOS are similar to those in other studies carried out with Physics teachers and students (Schwartz and Lederman, 2008; Shi and Wang, 2017; Vella Bondin, 2016) and were largely attributed to the mathematical basis of Physics that tends to make one perceive science as more absolute when compared to other disciplines (Vella Bondin, 2016).

Finally, NOS views were compared by highest qualification where they appeared to improve by higher qualification on four NOS components. However, this difference was only statistically significant when looking at the tentative nature of scientific theories. Here lecturers with a PhD exhibited significantly better views than those with a Masters or a Bachelors degree. Such a finding was attributed to a greater exposure to research, its subsequent subjective nature and the philosophical aspect that is many times emphasized when one is defending his/her doctoral thesis.

5.2. Implications for practice

In line with the findings by Vella Bondin (2016), where most science teachers exhibited adequate NOS views, as expected, most lecturers involved in this study held intermediate to adequate NOS views on most components. However, it is interesting to note that most lecturers like other stakeholders (Pace, 2014; Vella Bondin, 2016) in the area tended to have intermediate views on the distinction between scientific laws and theories. Such a finding was mostly evident in lecturers with a Physics background who tended to view science as more certain than other forms of knowledge. The use of the term 'law' in everyday language may lead one to associate science with certainty (Parker et al., 2008). The mathematical basis of Physics might have contributed to such a difference, even though the history of science shows that even physics laws, such as Newton's Laws of Motion, only apply within certain parameters. Feynman (1964), as cited in Crotty (2017), explains that tomorrow's experiment may prove what we thought was right as wrong. Considering the suggestion by Wong and Hodson (2008), one should rethink the use of the term 'law' in science as this tends to give a false sense of certainty. A more practical application of this in science classrooms is the approach taken when doing science experiments. One should realise that classroom experiments are not there to prove laws or show how science works in practice but are more of a theatrical performance to verify well-established knowledge (Wong and Hodson, 2008) while introducing basic scientific skills and principles to students.

Findings also show that a greater NOS component should be incorporated in applied science courses at the post-secondary level. While it is reasonable to place considerable emphasis on the practical application of science in these courses, both lecturers teaching in these courses as well as their students may occupy or would eventually occupy important positions in society. Subsequently a proper understanding of the NOS should be ensured as this is known to aid decision-making (Khishfe, 2012) and scientific literacy that ultimately enables one to function fully in a democratic society.

Findings also indicate that lecturers with higher academic qualifications tend to have better NOS views than those with lower qualifications. The recent national life-long learning strategy advocates a culture of life-long learning in Malta both through continuous professional development courses and further studies at post-graduate level (MEDE, 2020). The finding of this study continues to emphasize the importance of further academic achievement as it shows that this will contribute to better NOS understandings and hence better scientific literacy.

5.3. Strengths and limitations of the study

The major strength of this study is that the findings are based on two types of data sources, that is questionnaires and interviews. The quantitative nature of questionnaire findings coupled with the large number of both closed and open responses generated a greater reliability and external validity in this study, enabling the generalisation of the findings (Cohen et al., 2007). The open questions of the questionnaire coupled with the online interviews, in turn, increased the depth and hence the construct and internal validity of the findings (Cohen et al., 2007). Thus, the strength of this study lies in methodological triangulation that combines and converges multiple sources of data, hence viewing the same phenomenon from multiple perspectives (Johnston et al., 2007).

Notwithstanding, such a study also presented a number of limitations. To be able to draw a more generalised conclusion on NOS views held by lecturers one required the use of a ready-made questionnaire that enabled the measurement and eventual quantification of data on these views. The SUSSI questionnaire was developed and validated several times (Liang et al., 2006; 2008) and was widely used in both local (Pace, 2014; Vella Bondin, 2016) and international studies (Das et al., 2019; Karaman, 2017; Miller et al., 2010). While the introduction of open questions was intended to overcome the limitations of the Likert statements, these might have rendered the questionnaire somewhat difficult for some respondents. In fact, while a considerable number of responses was obtained, this might not be fully representative of all areassince some lecturers, especially those with limited background in the traditional sciences, might have found some of the questions difficult to answer, especially giving examples in the open responses.

Additionally, a number of studies (Dogan and Abd-El-Khalick, 2008; Griffiths and Barman, 1995; Park et al., 2013) indicate that NOS views may be influenced by culture. This might have been problematic when considering that the SUSSI questionnaire was developed and validated by international authors and therefore may not have been as sensitive to the Maltese context.

Another limitation emerged when comparing the views of pure science, applied science and humanities lecturers. Due to the diverse pathways that participants might have experienced to arrive at their current lecturing position, it was difficult to assign an exact classification between these three subgroups. Therefore, it was ultimately decided to leave it up to the lecturerher/himself to decide this. One should recognise that such classification may be somewhat subjective and might therefore limit the application of these findings.

5.4. Suggestions for future research

As explained in section 5.1, the findings of this study indicate that most lecturers have intermediate to adequate views on the NOS. Findings from open responses and interviews tended to corroborate the data from the close-ended items. Interestingly however, the inductive coding of interview responses yielded diversions on two NOS components. When asked to give examples on the social, cultural and political influence on science, more than half the participants mentioned conflict between science and social, cultural and political aspects. Regarding how scientific knowledge develops, only one participant mentioned diverse methods used in science. Participants were more inclined towards mentioning factors like coincidence, or a combination of things that ultimately led to discoveries and new scientific knowledge. Such responses may indicate that ready-made tools, especially the closed-items in the questionnaire may not incorporate all the views of all participants. Subsequently further studies utilising a more qualitative approach may give deeper descriptions on the NOS views of various stakeholders in Malta, including scientists in diverse fields and younger students. While adopting a more anti-realist theoretical position, such studies can adopt a more pluralistic definition of the term NOS which will incorporate diverse ideas (Wong and Hodson, 2008).

Further research can also be carried out on the NOS views of younger students who attend compulsory education. Aside from investigating their NOS ideas, one can also study factors that may affect these views such as parental involvement, science capital and socio-economic status. Such factors were found to effect NOS views of students on an international level (Abd-El-Khalick and BouJaoude, 2003; Hacieminoglu et al., 2015)

Another area which would require further investigation is the implementation of NOS aspects in Maltese science classrooms. While studies have investigated the NOS views of various stakeholders in the area, no study has yet tried to implement or teach aspects of the NOS to Maltese students at any level. As Vella Bondin (2016) argues one cannot assume that by having adequate NOS views teachers will automatically translate such views into classroom practice. Such studies may be carried out with students who attend compulsory educational or post-secondary institutions. They may use diverse approaches such as a context-based, explicit-reflective approach, an implicit approach or aspects of the history of science. Interviews and questionnaires can be used to measure the effectiveness of implementing these NOS aspects in a Maltese context.

Subsequently the following is a possible list of studies that can be carried out in the area:

- The NOS views of Maltese secondary school students in a particular year group.
- The effectiveness of an explicit-reflective approach in teaching the NOS to Maltese secondary science students.
- The effectiveness of history of science stories to implement aspects of the NOS in Maltese secondary science classrooms.
- The effectiveness of a NOS course in implementing NOS with Maltese science undergraduates.
- A qualitative investigation of the NOS views of Maltese scientists.

5.5. Conclusion

The above study provided valuable insights on the NOS views of Maltese lecturers. While it showed a few differences between some of the subgroups investigated, it showed a great similarity on most NOS components.

The considerable percentage of adequate views in the majority of lecturers as well as science teachers (Vella Bondin, 2016) is a promising result which indicates that locally we have already made the initial steps and gained good ground towards adequate NOS views and scientific literacy.

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APPENDICES

Appendix A: Questionnaire

Online Information Sheet Lecturer

Dear Sir/Miss,

My name is Rachel Pace and I am currently reading for an M.Ed. in Science Education. I am carrying out a research study entitled 'Maltese Post-Secondary Lecturers' Views on the Nature of Science'. This study aims to investigate the Nature of Science views held by Maltese post-secondary lecturers and how these views compare and contrast depending on area of specialisation. My dissertation supervisor is Dr Martin Musumeci.

Subsequently I would be very grateful if you, as a current lecturer, can participate in this study by answering the questionnaire below. It will take approximately 30 minutes to fill in. This questionnaire is not a test, consequently there are no right or wrong answers. You are only asked to give your personal views. The open-ended question at the end of each section enables you to explain further your views expressed in the corresponding first part. Your participation is anonymous and the results obtained will only be used for research purposes. You will not be asked to write your name on the questionnaire and the survey being used will not collect IP addresses, and subsequently you will remain anonymous.

You are not obliged to participate, however your contribution will be much appreciated. If you accept to participate, please proceed to the link below.

Thank you for your time.

Yours sincerely,

Rachel Pace

Student Understanding of Science and Scientific Inquiry Questionnaire

Questions adapted from: (Liang, Chen, Chen, Kaya, Adams, Macklin and, Ebenezer, 2008).

Please answer all questions. Thank you for your contribution to the study. Rachel Pace.

Section A: Please fill in the details below:

1. Gender

   A. Male B. Female

2. Age Group

   A. 20-29 B. 30-39 C. 40-49

   D. 50-59 E. 60-69 F. Above 70

3. How many overall years of teaching/lecturing experience do you have?

   A. 1-5 years B. 6-10 years C. 11-15 years

   D. 16-20 years E. 21-25 years F. 26 years or more

4. Where do you currently give lectures? (You may choose more than one option.)
   - University of Malta
   - 6^{th} Form
   - MCAST
   - Secondary level
   - Others

5. Do you give most lectures in:
   - Pure science
   - Applied Science
   - Humanities

6. To which traditional area is your specialisation closest to:
    - Physics
    - Chemistry
    - Biology
    - Humanities

7. What is your highest academic qualification?
    - Bachelors
    - Masters
    - PhD

8. What is your highest qualification in each science subject?

    a. Physics
        - Less than O level
        - O level
        - Intermediate
        - A level
        - University
    b. Chemistry
        - Less than O level
        - O level
        - Intermediate
        - A level
        - University
    c. Biology
        - Less than O level
        - O level
        - Intermediate
        - A level
        - University

Section B: Please read **EACH** statement carefully, and then indicate the degree to which you agree or disagree with **EACH** statement by circling the appropriate letters to the right of each statement.

- SD = Strongly Disagree
- D = Disagree
- U = Uncertain
- A = Agree
- SA = Strongly Agree.

1. Observations and Inferences

A	Scientists' observations of the same event may be different because the scientists' prior knowledge may affect their observations.	SD	D	U	A	SA
B	Scientists' observations of the same event will be the same because scientists are objective.	SD	D	U	A	SA
C	Scientists' observations of the same event will be the same because observations are facts.	SD	D	U	A	SA
D	Scientists may make different interpretations based on the same observations.	SD	D	U	A	SA
Explain why you think that scientists' observations and interpretations of the same event are the same **OR** different? You may provide examples to support your answer.						

2. Change of Scientific Theories

A	Scientific theories are subject to on-going testing and revision.	SD	D	U	A	SA
B	Scientific theories may be completely replaced by new theories in light of new evidence.	SD	D	U	A	SA
C	Scientific theories may be changed because scientists reinterpret existing observations.	SD	D	U	A	SA
D	Scientific theories based on accurate experimentation will not be changed.	SD	D	U	A	SA
Explain why you think scientific theories change **OR** do not change over time? You may provide examples to support your answer.						

3. Scientific Laws vs. Theories

A	Scientific theories exist in the natural world and are uncovered through scientific investigations.	SD	D	U	A	SA
B	Unlike theories, scientific laws are not subject to change.	SD	D	U	A	SA
C	Scientific laws are theories that have been proven.	SD	D	U	A	SA
D	Scientific theories explain scientific laws.	SD	D	U	A	SA
Explain what are scientific theories and scientific laws and how they are different. You may provide examples to support your answer.						

4. Social and Cultural Influence on Science

A	Scientific research is not influenced by society and culture because scientists are trained to conduct pure, unbiased studies.	SD	D	U	A	SA
B	Cultural values and expectations determine <u>what</u> science is conducted and accepted.	SD	D	U	A	SA
C	Cultural values and expectations determine <u>how</u> science is conducted and accepted.	SD	D	U	A	SA
D	All cultures conduct scientific research in the same way because science is universal and independent of society and culture.	SD	D	U	A	SA
Explain how society and culture affect **OR** do not affect scientific research. You may provide examples to support your answer.						

5. Imagination and creativity in Scientific Investigations.

A	Scientists use their imagination and creativity in both the method and the collection of data.	SD	D	U	A	SA
B	Scientists use their imagination and creativity when they analyze and interpret data.	SD	D	U	A	SA
C	Scientists do **not** use their imagination and creativity because these conflict with their logical reasoning.	SD	D	U	A	SA

D	Scientists do **not** use their imagination and creativity because these can interfere with objectivity.	SD	D	U	A	SA
Explain whether scientists use **OR** do not use their imagination and creativity. You may provide examples to support your answer.						

6. Methodology and Scientific Investigation

A	Scientists use different types of methods to conduct scientific investigations.	SD	D	U	A	SA
B	Scientists follow the same step-by-step scientific method.	SD	D	U	A	SA
C	When scientists use the scientific method correctly, their results are true and accurate.	SD	D	U	A	SA
D	Experiments are not the only means used in the development of scientific knowledge.	SD	D	U	A	SA
Explain whether scientists follow a single, universal scientific method **OR** use different types of methods. You may provide examples to support your answer.						

Thank you

Appendix B: Interview

Interview Protocol

Good morning/ afternoon.

My name is Rachel Pace and I am currently reading for an M.Ed. in Science Education. As part of my dissertation I am carrying out a research study among post-secondary lecturers.

This research is concerned with acquiring an understanding of lecturers' views on the nature of science. Firstly, I would like to thank you for participating in my research through this interview. Your input is greatly appreciated and shall make a contribution to science education.

I would like to remind you that your participation is voluntary, and your responses will be treated with confidentiality. The recordings shall be destroyed once the study is over. You can also refrain from answering particular questions without justification.

There are no right or wrong answers to the questions which I will be asking you. I am only interested in your perspective about science.

If you agree to participate please give your verbal consent as soon as I start the recording. You basically have to state that you have read and understood the participant information sheet and agree to participate in this interview. You give consent for audio-recording and the use of anonymous quotations while writing the research.

With your permission I will now start recording this interview.

(Start record)

Main Question	Probe/Prompt
1) Mark whether participant is male (M) or female (F)	
2) Can you please describe your teaching experience?	What institution do you teach in? For how many years have you been teaching?
3) What is your area of specialisation?	Do you consider it a pure science, an applied science or a humanities area?
4) What is your area of specialisation closest to, if any out of the three main sciences or the humanities?	Biology/ Chemistry/ Physics/ Humanities
5) What is your highest qualification in each science subject? Whether it is less than O level, O level, intermediate, A' level or University.	Biology: ___________________________ Chemistry: _________________________ Physics: ___________________________
6) What is your highest academic qualification? Bachelors, Masters or PhD?	Can you specify in which area?
7) Can you please indicate your age bracket? Whether it is 20-29, 30-39, 40-49, 50-59 or 60-69.	
a. Nature of Science Questions (adopted from VNOS- Form C)	
8) In your opinion, what makes science different from other forms of knowledge like art, philosophy and religion?	
9) In your opinion what brings about the development of new scientific knowledge?	Is it experiments?
10) After scientists have developed a scientific theory, like evolutionary theory or atomic theory, does the theory ever change?	If yes, explain why and how theories change. If no, give a reason for your answer

11) Is there a difference between a scientific theory and a scientific law?	Can you give an example?
12) Science textbooks represent the atom as being made of protons, electrons and neutrons. How certain are scientists of this model?	What evidence do scientists have of what the atom looks like?
13) Can scientists come to a different conclusion using the same set of data? How? Why?	For example, a theory claims that dinosaur extinction was caused by a meteorite that hit the Earth. Another theory based on the same evidence claims that extinction was brought about by volcanic eruptions. Both theories are based on the same sources of data.
14) Do scientists use imagination and creativity when doing science?	If yes, in which part or parts?
15) In your opinion is science influenced by social, cultural and political values?	Can you give an example?

Appendix C

Permission Letter- Heads of 6th Form

Dear Headmaster,

I am Rachel Pace and I am currently reading for an M.Ed. in Science Education at the University of Malta. As part of this course I will be carrying out a research study in order to write a dissertation. My dissertation supervisor is Dr. Martin Musumeci.

The title of my dissertation is 'Maltese Post-Secondary Lecturers' Views on the Nature of Science'. The aim of this study is to investigate post-secondary lecturers' views on the nature of science and how these compare and contrast depending on area of specialisation.

The study shall consist of two parts. The first part is an online survey that will be disseminated amongst post-secondary lecturers teaching in particular areas. The second part of the study involves an interview with up to two lecturers from these areas and which will take around 30 minutes. Subsequently I am kindly asking for your permission to allow part of this research study to be conducted in your school.

Should you give me permission I would ask you to kindly distribute the attached questionnaire to a number of lecturers by email. These will be lecturers teaching the following subjects: biology, chemistry, pure mathematics, geography, physics, applied mathematics, computing, environmental science, information technology, philosophy and religious knowledge. The questionnaire contains questions about the nature of science and should take approximately 20 minutes to complete. This questionnaire can be filled online on Google Forms. If possible, I would also ask you to let me know to how many lecturers it was distributed.

Following this I would also invite up to two lecturers from your school to kindly participate in an online interview which will also take approximately 30 minutes. I will contact these lecturers myself via email. The focus of the interview questions will also be their nature of science views. With their consent these interviews will be audio-recorded as I would need to transcribe their responses in order to analyse them.

Participation in both questionnaire and interview is voluntary and participants can withdraw from answering parts or all of the questionnaire or interview. Participants will not be required to write their names on the questionnaire and the survey being used will not collect IP addresses. The identity of each participant and that of the school will be kept confidential. The identity of interview participants will be anonymised in my write-up through the use of a pseudonym.

All raw data will be encrypted with password, shall be stored on an external hard drive and will be solely used for the compilation of my dissertation. All data will be destroyed after my graduation.

I would like to assure you that I will abide by the ethical guidelines issued by the University Research Ethics Committee of the University of Malta throughout the course of this research.

If you accept to participate in this research, kindly send your permission by replying to this email. If you require more information, please do not hesitate to contact me. Thank you in advance for your kind consideration.

Yours sincerely,

RACHEL PACE

Mobile Number: [redacted]

Email Address: [redacted]

Supervisor's Details:

Name: Dr M. Musumeci

Office No.: [redacted]

Email: [redacted]

Permission Letter: Secretariat for Catholic Education

To whom it may concern,

I am Rachel Pace, a student reading for an M.Ed. in Science Education at the University of Malta. As part of this course I will be carrying out a research study in order to write a dissertation. My dissertation supervisor is Dr. Martin Musumeci.

The title of my dissertation is ‘Maltese Post-Secondary Lecturers’ Views on the Nature of Science’. For this study I will be investigating the nature of science views held by local post-secondary lecturers and how these compare and contrast depending on area of specialisation. I would be very grateful if you would give me permission to conduct part of this research study at your sixth forms.

Should permission be granted, I would like to ask the heads of sixth forms to distribute a link to an online questionnaire to lecturers of science and some other subjects in each school. This will contain questions about the nature of science and will take approximately 20 minutes to complete. Following this, I will invite up to two lecturers from participating schools to take part in an online interview. Once again, the interview will be on their nature of science views and will take up to 30 minutes. You can find attached a copy of both the questionnaire, interview questions and lecturers’ consent forms.

Participation is voluntary. I will first ask the respective Heads of school for their kind permission to carry out data collection in their schools. Following this I will also forward an information letter and consent form to participant lecturers. Lecturers may choose not to complete parts or all of the questionnaire and/or interview. They will not be asked to write their names on the questionnaire, subsequently they will remain anonymous. Interview participants and their respective school will remain anonymous through the use of pseudonyms. All raw data will be securely stored and the data will solely be used for research purposes.

I would like to assure you that I will abide by the ethical guidelines issued by the University Research Ethics Committee of the University of Malta throughout the course of my research.

Should you require further information, please do not hesitate to contact me or my supervisor through the contact details below.

Thank you for your kind consideration.

Yours sincerely,

RACHEL PACE

Mobile Number: [redacted]

Email Address: [redacted]

Postal Address: [redacted]

Supervisor's Details:

Name: Dr M. Musumeci

Office No.: [redacted]

Email: [redacted]

Permission Letter- MCAST Directors

Dear Director,

I am Rachel Pace, a student reading for an M.Ed. in Science Education at the University of Malta. As part of this course I will be carrying out a research study in order to write a dissertation. My dissertation supervisor is Dr Martin Musumeci.

The title of my dissertation is 'Maltese Post-Secondary Lecturers' Views on the Nature of Science'. For this study I will be investigating the nature of science views held by local post-secondary lecturers and how these compare and contrast depending on area of specialisation. I would be very grateful if you would give me permission to conduct part of this research study at your institute.

Should permission be granted, I would like to ask you to kindly distribute an online questionnaire to your lecturers. This will contain questions about the nature of science and will take approximately 20 minutes to complete. This questionnaire can be filled online on google forms. If possible, I would also ask you to let me know to how many lecturers it was distributed.

Following this I would ask up to two lecturers to participate in an online interview. I shall contact these lecturers myself via email. Once again, the interview will be on their nature of science views and will take up to 30 minutes.

Participation is voluntary. An information letter and consent form will be forwarded toparticipant lecturers. Lecturers may choose not to complete parts or all of the questionnaire and/or interview. They will not be asked to write their names on the questionnaire and the survey being used will not collect IP addresses, subsequently they will remain anonymous. The names of interview participants and their respective institute will be kept confidential through the use of pseudonyms. All raw data will be encrypted with password, shall be securely stored on an external hard drive and will solely be used for research purposes. All data will be destroyed after my graduation.

I would like to assure you that I will abide by the ethical guidelines issued by the University Research Ethics Committee of the University of Malta throughout the course of my research.

If you accept to participate in this research, **kindly send your permission by replying to this email.**Should you require further information, please do not hesitate to contact me or my supervisor through the contact details below.

Thank you for your kind consideration.

Yours sincerely,

RACHEL PACE

Mobile Number: [redacted]

Email Address: [redacted]

Supervisor's Details:

Name: Dr M. Musumeci

Office No.:[redacted]

Email: [redacted]

Permission Letter- UOM

To whom it may concern,

I am Rachel Pace, a student reading for an M.Ed. in Science Education at the University of Malta. As part of this course I will be carrying out a research study in order to write a dissertation. My dissertation supervisor is Dr Martin Musumeci.

The title of my dissertation is 'Maltese Post-Secondary Lecturers' Views on the Nature of Science'. For this study I will be investigating the nature of science views held by local post-secondary lecturers and how these compare and contrast depending on area of specialisation. I would be very grateful if you would give me permission to conduct part of this research study at the University of Malta.

Should permission be granted, I would like to ask you to kindly distribute an online questionnaire to a number of lecturers. You can find attached a list of all the faculties, centres and institutes to whom I need to send the questionnaire. If possible, I would also ask you to let me know the number of lecturers to whom it will be distributed so I can calculate the sample size. All questions in the questionnaire will be about the nature of science and will take approximately 20 minutes to complete. Following this I would ask up to five lecturers to participate in an online interview. I shall contact these lecturers myself via email. Once again, the interview will be on their nature of science views and will take up to 30 minutes.

Participation is voluntary. An information letter and consent form will be forwarded to participant lecturers. Lecturers may choose not to complete parts or all of the questionnaire and/or interview. They will not be asked to write their names on the questionnaire and the survey being used will not collect IP addresses, subsequently they will remain anonymous. The names of interview participants and their respective institute/faculty will be kept confidential through the use of pseudonyms. All raw data will be encrypted with password, shall be securely stored on an external hard drive and will solely be used for research purposes. All data will be destroyed after my graduation.

I would like to assure you that I will abide by the ethical guidelines issued by the University Research Ethics Committee of the University of Malta throughout the course of my research.

Kindly let me know if you would like to participate in this research by sending permission to this email. Should you require further information, please do not hesitate to contact me or my supervisor through the contact details below.

Thank you for your kind consideration.

Yours sincerely,

RACHEL PACE

Mobile Number: [redacted]

Email Address: [redacted]

Supervisor's Details:

Name: Dr M. Musumeci

Office No.: [redacted]

Email: [redacted]

Appendix D

Information Letter- Lecturer

Dear lecturer,

I am Rachel Pace and I am currently reading for an M.Ed. in Science Education at the University of Malta. As part of this course I will be conducting a research study entitled 'Maltese Post-Secondary Lecturers' Views on the Nature of Science' under the supervision of Dr. Martin Musumeci. Through this research I will be investigating the nature of science views held by Maltese post-secondary lecturers and how these vary depending on area of specialisation.

I would like to invite you to participate in my research study. This involves an interview about your nature of science views which will take approximately 30 minutes to complete. Questions will be about science as a discipline, how new scientific knowledge develops and how it compares to other forms of knowledge.

Should you choose to participate, the interview will be held online using Microsoft Teams or Zoom on a day and time convenient for you.With your signed consent and an online declaration that you have read and understood this letter, the interview will be audio-recorded as I would need to transcribe your responses in order to analyse them.

I will keep your identity and that of the institution confidential, as both will be anonymised in my write-up through the use of pseudonyms. Participation is voluntary and you are free to withdraw from the study at any time. As a participant, you have the right, under the General Data Protection Regulation (GDPR) and national legislation that implements and further specifies the relevant provisions of said regulation, to access, rectify and where applicable ask for the data concerning you to be erased. Should you choose to do this, your interview data will not be used for the study and will be destroyed.

The recorded data will be encrypted with password, shall be securely stored on an external hard drive and will only be accessed by myself. Recordings will be used for the purpose of transcription; once I have transcribed the interview I will destroy the audio-recording.

If you agree to participate in this interview, kindly complete the attached consent form and send a photo or scanned copy of it on the email address below.

If you require further information, do not hesitate to contact me or my supervisor.

Yours sincerely,

Rachel Pace
Mobile Number: [redacted]
Email Address: [redacted]

Supervisor: Dr M. Musumeci
Office Number: [redacted]
Email Address: [redacted]

Consent Form Lecturer

Maltese Post-Secondary Lecturers' Views on the Nature of Science

I confirm that I have read the attached *Participant Information Sheet* for this study and that I have had the opportunity to ask questions and discuss the study.

On the basis of the information given, I agree to allow Ms. Rachel Pace to:

- Carry out an audio-recorded interview about my nature of science views.
- Use anonymous quotations throughout the write-up of her dissertation.

I give consent to Ms. Rachel Pace to carry out the interview for this study.

_______________________ ____________________________ __________________________

Lecturer's Name Lecturers' signature Lecturers' contact email

Date: ____________________

Researcher's signature: 

Mobile Number: [redacted]

Email Address: [redacted]

Appendix E: Rubric used to classify responses (Liang et al., 2009 as cited in Miller et al., 2010)

Component	Unclassifiable	Inadequate	Intermediate	Adequate
1: Observations and Inferences	No response. OR Response does not address the prompt. OR Response cannot be classified based on the rubric.	Observations and/or inferences of different scientists are the same because science is factual/ objective	Scientists' observations or inferences are different because these are influenced by the scientists' prior experience and knowledge OR Both observations and interpretations are distinct but no justifiable reason is given	Observations and inferences can be different as they are influenced by current beliefs in science or the scientists' previous experience
2: Change of Scientific Theories	No response. OR Response does not address the prompt. OR Response cannot be classified based on the rubric.	Scientific theories are objective and do not change by time especially if they are proven by accurate experimentation or facts	Scientific theories may change if equipment is improved or new evidence is found	Scientific theories may change over time due to improved technology, new evidence or reinterpretation of existing observations.
3: Scientific Laws vs. Theories	No response. OR Response does not address the prompt. OR Response cannot be classified based on the rubric.	Scientific laws are superior to scientific theories as they are more certain. Proved scientific theories become laws.	Laws and theories are not a human construct but are found in nature.	Scientific laws and scientific theories are two distinct forms of knowledge that are subject to change. A scientific theory may explain a scientific law but not every law has an accompanying theory.
4: Social and Cultural Influence on Science	No response. OR Response does not address the prompt. OR Response cannot	Science tries to discover a universal truth and thus is not effected by society and culture	Scientists are effected by society and culture in some aspects of scientific investigation	Society and culture influence which and how science is carried out.

	be classified based on the rubric.			
5: Imagination and Creativity in scientific Investigations	No response. OR Response does not address the prompt. OR Response cannot be classified based on the rubric.	Science is objective, thus scientists do not use imagination and creativity when conducting science.	Scientists only use imagination and creativity in some aspects of scientific investigation but not throughout the investigation.	Scientists use imagination and creativity throughout the whole process of scientific investigation.
6: Methodology and Scientific Investigation	No response. OR Response does not address the prompt. OR Response cannot be classified based on the rubric.	There is only one, universal, step-by-step method which is universal and is used for scientific investigations	Scientists may use a number of methods but confirmation of results requires the use of a universal scientific method.	There is no universal scientific method. Scientists use different methods of investigation depending on what science is being conducted.

Appendix F

The tables and graphs below show the results on all six SUSSI components for age group and lecturing experience. One notes that no statistically significant difference was found between any of these groups.

		N	Mean	Std. Deviation	*p* value
Observations and Inferences	20-29	16	3.83	.416	0.512
	30-39	69	3.52	.792	
	40-49	79	3.55	.736	
	50-59	59	3.49	.835	
	60 and above	29	3.67	.889	
Change of Scientific Theories	20-29	16	4.05	.518	0.126
	30-39	69	3.92	.688	
	40-49	79	3.92	.562	
	50-59	59	4.00	.575	
	60 and above	29	4.16	.806	
Scientific Laws vs. Theories	20-29	16	3.00	.658	0.740
	30-39	69	2.89	.695	
	40-49	79	2.87	.566	
	50-59	59	2.81	.551	
	60 and above	29	2.89	.686	
Social and Cultural Influence on Science	20-29	16	3.69	.854	0.910
	30-39	69	3.59	.826	
	40-49	79	3.65	.805	
	50-59	59	3.61	.829	
	60 and above	29	3.75	.845	
Imagination and Creativity in Scientific Investigation	20-29	16	3.75	.885	0.932
	30-39	69	3.53	.996	
	40-49	79	3.70	.846	
	50-59	59	3.64	.743	
	60 and above	29	3.52	1.073	
Methodology and Scientific Investigation	20-29	16	3.72	.482	0.628
	30-39	69	3.63	.571	
	40-49	79	3.58	.544	
	50-59	59	3.72	.604	
	60 and above	29	3.77	.630	

Table 0.1:Kruskal Wallis test for the close-ended responses by age group

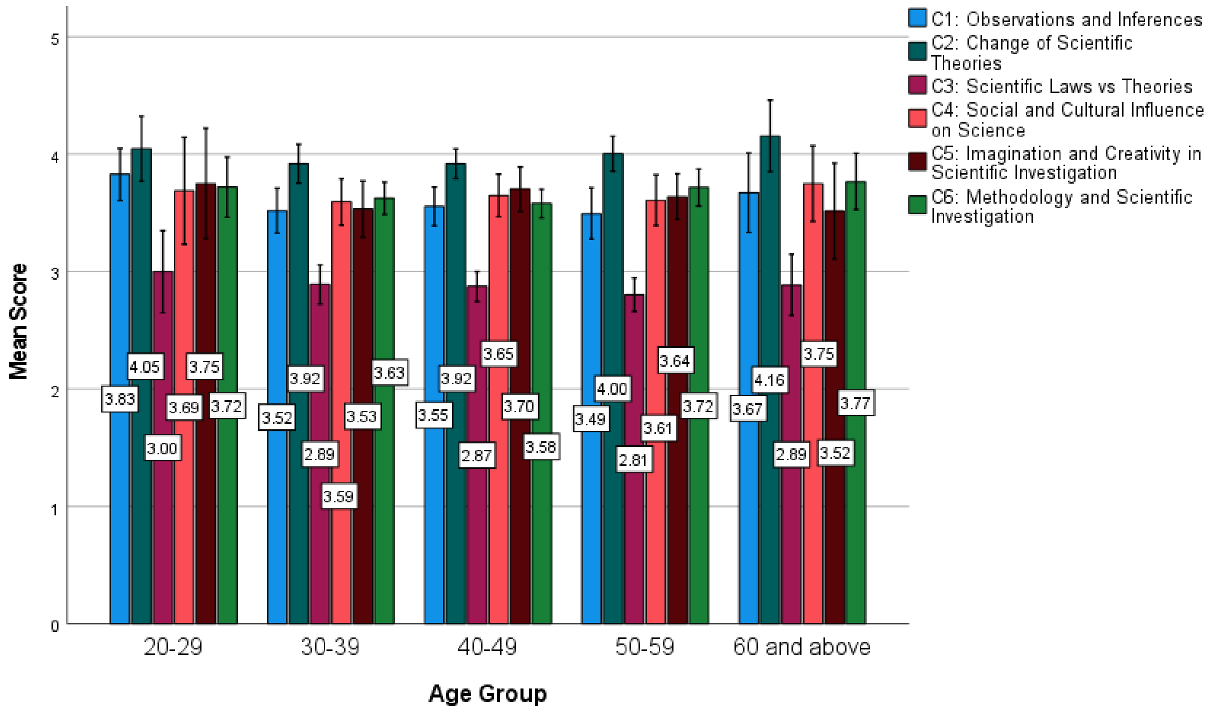

Figure 0.1: An error bar graph showing the mean score on all NOS components by age group

		N	Mean	Std. Deviation	*p* value
Observations and Inferences	1-5 years	29	3.69	.611	0.391
	6-10 years	51	3.53	.728	
	11-15 years	38	3.39	.794	
	16-20 years	40	3.69	.787	
	21-25 years	37	3.65	.761	
	26 years or more	57	3.48	.882	
Change of Scientific Theories	1-5 years	29	4.01	.610	0.336
	6-10 years	51	3.86	.649	
	11-15 years	38	4.04	.662	
	16-20 years	40	3.94	.466	
	21-25 years	37	3.98	.623	
	26 years or more	57	4.04	.712	
Scientific Laws vs. Theories	1-5 years	29	2.96	.710	0.797
	6-10 years	51	2.87	.575	
	11-15 years	38	2.86	.682	
	16-20 years	40	2.79	.604	
	21-25 years	37	2.90	.573	
	26 years or more	57	2.88	.615	
Social and Cultural Influence on Science	1-5 years	29	3.74	.783	0.795
	6-10 years	51	3.60	.844	
	11-15 years	38	3.53	.815	
	16-20 years	40	3.78	.725	
	21-25 years	37	3.65	.751	
	26 years or more	57	3.59	.930	
Imagination and Creativity in Scientific Investigation	1-5 years	29	3.71	.996	0.509
	6-10 years	51	3.65	.828	
	11-15 years	38	3.36	.920	
	16-20 years	40	3.60	.847	
	21-25 years	37	3.72	.845	
	26 years or more	57	3.69	.949	
Methodology and Scientific Investigation	1-5 years	29	3.69	.436	0.381
	6-10 years	51	3.51	.639	
	11-15 years	38	3.61	.482	
	16-20 years	40	3.66	.486	
	21-25 years	37	3.77	.535	
	26 years or more	57	3.71	.689	

Table 0.2: Kruskal Wallis test for the close-ended responses by lecturing experience

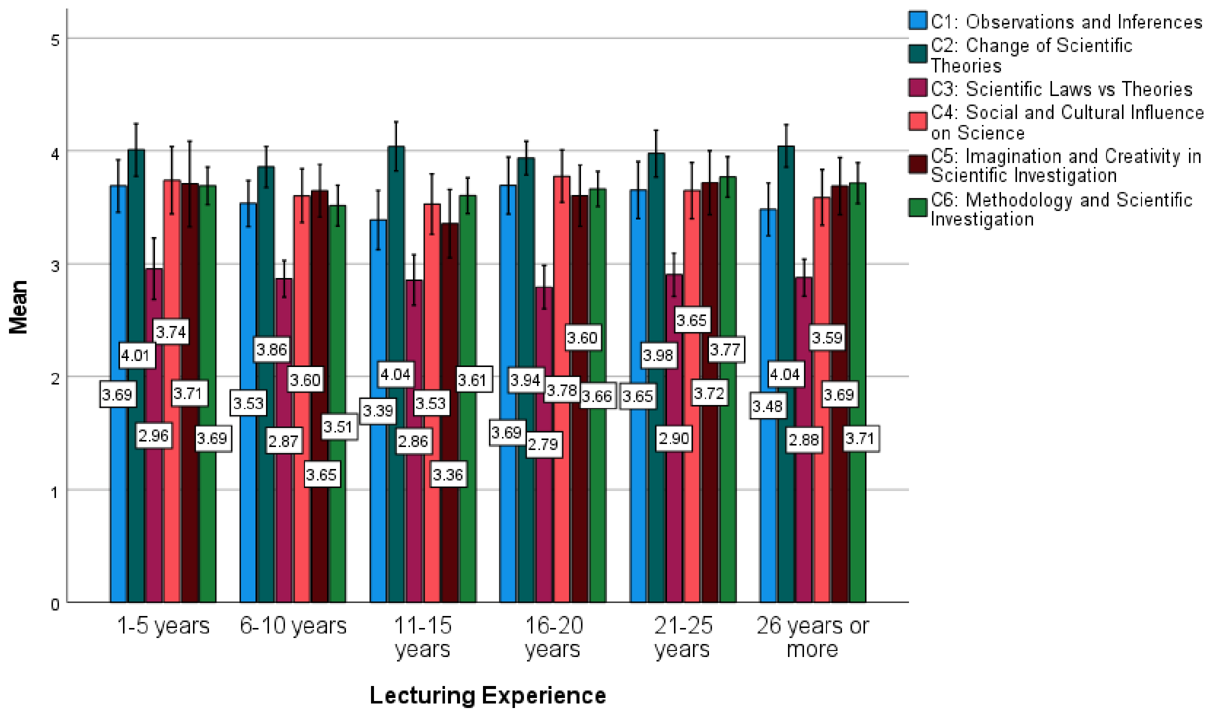

Figure 0.2: An error bar graph showing the mean score on all NOS components by lecturing experience