WONDER WILD: A PHILOSOPHICAL APPROACH TO UNDERSTANDING TEACHERS' AND CHILDREN'S SOCIAL REPRESENTATIONS OF SCIENCE

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September 2023

Abstract

Currently we know very little about how primary school children and teachers perceive science and its nature. The aim of this study is to gain understanding by conducting a community of inquiry approach through philosophical dialogues in focus groups with children, and interviews and focus groups with teachers. This is to explore the hidden assumptions that children and teachers have about nature of science. The participants were children of year 5 from three Maltese schools and their primary school teachers. Social representations were explored using a central approach to social representations characterised by the main idea being discussed in dialogue and the meanings that children and teachers attach to the idea. This analysis of social representations indicate five social representations from teachers' dialogue and a total of six social representations from children's philosophical dialogue. There seems to be common ideas between children's and teachers' social representations of nature of science including the view that science is an activity by which scientists study, discover and understand the world in a precise and reliable way. There is agreement amongst children and teachers on some characteristics of science mainly that scientific evidence derives from both observation and experimentation, two scientific methods which took precedence in children's talk about science. The findings within this research are useful to understand the images that children and teachers have about the nature of science to identify any challenges and concerns which may impede science learning and thus enable teachers and policy makers to meet the needs of the learners.

Key words: science, philosophy of science, nature of science, education

Contents

Acknowledgements

Firstly, I would like to express my deepest gratitude and appreciation to my supervisor, Dr. Lynda Dunlop, for her continuous support, patience and motivation throughout this Ph.D. I could not imagine having a better supervisor and mentor.

This endeavour would not have been possible without the insight and guidance of my thesis advisory panel, most especially Prof. Kathryn Asbury for her invaluable insight and feedback.

I gratefully acknowledge the funding received towards my Ph.D to the Maltese Ministry for Education, Sport, Youth, Research and Innovation under the Tertiary Education Scholarship (TESS) for funding this Ph.D study.

I am extremely grateful for all the people who have contributed to this study, most especially the children, teachers, parents and heads of school who have so generously dedicated their time to take part in this research.

I am extremely grateful for my friends, especially my teacher friends who have participated in the pilot study and who have kept me going with their ongoing support. I would like to thank Smriti Safaya who I was lucky enough to be working alongside during this Ph.D. and my wonderful friend and writing buddy Jessica Breese for all the wonderful writing retreats and chats we had along the way.

Last but not least, a big thank you goes to my number one supporter, my mum. Her belief in me has kept my motivation high during this journey.

Dedication

This dissertation is dedicated in memory of my grandparents, Emmanuel Vella (1945-2015) and Hilda Vella (1950-2022) for encouraging me to do my best and for constantly believing in me. My grandfather have instilled in me a great passion for learning, and a love for science. May their memory forever be a comfort and a blessing. They were the best grandparents someone could ever have.

I DECLARE THAT THIS THESIS IS A PRESENTATION OF ORIGINAL WORK AND I AM THE SOLE AUTHOR. THIS WORK HAS NOT PREVIOUSLY BEEN PRESENTED FOR AN AWARD AT THIS, OR ANY OTHER, UNIVERSITY. ALL SOURCES ARE ACKNOWLEDGED AS REFERENCES.

Chapter 1

Introduction

1.1 What is Nature of Science?

Science holds a privileged epistemic position in society (West & Bergstrom, 2021). The value that science has in society can be identified through the language that the public uses to talk about science (Stilgoe, Lock & Wilsdon, 2014). While there is an epistemic trust in science, the public still relies on social media and search engines to find information. This has resulted in falsehoods of information being passed from untrustworthy sources (West & Bergstrom, 2021). With the impact of Covid, we have seen many concerns with regards to misinformation (Scheufele & Krause, 2019; West & Bergstrom, 2021). According to West and Bergstrom (2021), misinformation refers to spreading information that is not true or accurate- for example due to issues with sampling, misaligned incentives and/or reliance on outdated information. As a result of misinformation we currently find ourselves in an 'infodemic' where we are continuously fighting against misinformation or fake news (Scheufele, Krause & Freiling, 2021). In recent times, discussions on misinformation have taken somewhat centre stage in light of Coronavirus and vaccines (Parker, Byrne, Goldwater & Enfield, 2021). Science is one discipline which is being targeted and exploited to warrant public misinformation (Allchin, 2023; Goldstein, Murray, Beard, Schnoes & Wang, 2020; Lewandowsky et al., 2022). Many false claims are being made in the name of science to control the public into thinking that what is being said is trustworthy knowledge (West, 2021).

In order for collective action to be successful, misinformation must be addressed (West & Bergstrom, 2021). The importance of having good understanding of science stems from the need for the public to be aware of the nature of scientific research; how it is designed, interpreted, disseminated and ultimately justified. This calls for the need to educate the public on what we call 'nature of science'. Nature of science (NoS) refers to the characteristics, processes and aspects of science (Chalmers, 2013; Smith et al., 1997). A good understanding and awareness of the epistemic position of science helps the public to seek reliable information and make more informed choices such as in the case of vaccines.

Modern life is shaped by science in countless ways from what we eat, the technology we use and the healthcare that we receive. In spite of this tremendous impact, few people have a basic understanding of how science works (Huber et al., 2019; Irwin, 2014; Lazer et al., 2018). The lack of understanding can have harmful consequences such as vaccine hesistancy (Goldenberg, 2016), particularly in societies where citizen participation is encouraged in science funding decisions, policy evaluation, and societal issues like climate change and vaccinations that weigh scientific evidence (Sinatra, Kienhues & Hofer, 2014). For example, some people have been reluctant to get vaccinated against Covid or vaccinate their children against harmful diseases as a result of the misinformation that they have received and chose to believe (Goldenberg, 2021). Misunderstandings about the nature of science underlie many irrational decisions and unreasonable positions (Huber et al., 2019; McComas, Clough & Almazroa, 1998). This includes making uninformed decisions as a result of lack of knowledge and understanding about the way science works.

1.2. Why nature of science matters for science education

The years of compulsory schooling is an important time to educate the public about how science works, its strengths, limits and limitations (Weisberg et al., 2021). This need is even important in primary education when children are beginning to understand the role that science plays in society and have started to engage in scientific information through the general public, both at school as well as in the community (Rousell & Cutter-MacKenzie-Knowles, 2020).

There is an increasing interest for nature of science to make its way into science education (Lederman, 2013; Erduran & Dagher, 2014). Since the mid-twenty first century, there has been significant efforts towards defining nature of science in educational terms, incorporatingit into curricula, and imparting the nature of scientific knowledge and skills to children and teachers (Lederman, 2013; Matthews, 2014; National Research Council, 1996; National Research Council, 2000). This occupies an uneasy place in science education as nature of science is essentially philosophy rather than science, and can present a challenge to teachers in educational settings (especially in some countries like England where philosophy is absent from compulsory education).

1.3. How Nature of Science contributes to scientific literacy

Literature within the nature of science (Leckie, 2017; Allchin, 2014; Lestari, Setiawan & Siskander, 2020) has consistently addressed the role that nature of science plays in enhancing scientific literacy.

There are different variations and meanings behind the term scientific literacy. For example, Holbrook and Rannikmae (2009) define scientific literacy as the appreciation and understanding of science for an individual to function as an active citizen. As the excerpt from the National Curriculum in Malta (2011) illustrates, scientific literacy is the core aim to addresses the need for learners to have good understanding of science and the way it functions in society.

> *It is important to develop the scientific literacy of all learners, enabling them to make informed decisions as they strive to improve their quality of life and to understand the changing contexts. Knowledge of science affects the choices we make for healthy living; the prevention and treatment of disease; energy use and living in safe and comfortable homes; transport and communicating with others; and other everyday life decisions. Science also helps us to answer questions that have intrigued human beings for many years and which are still unresolved…Science education provides an opportunity for learning what scientists have done and what they are doing to answer these questions and enables children to consider the ethical and moral implications of science. Furthermore, scientific literacy empowers citizens to initiate change and actively participate in decision making fora. Besides imparting knowledge, science education also develops skills and ways of thinking that are important for decision-making and problem solving using an evidence-based approach. These include inquiry, observation and accurate measurement, critical thinking, considering alternative interpretations, and communicating conclusions. An education in science also serves*

to develop and strengthen attitudes and values that are important for living in a democratic society.

(p.25)

In the latest report of 'The Trends in International results in Mathematics and Science Study' (TIMMS) 2019; which assesses the knowledge and skills of children's maths and science achievements, Malta came up in the 36th place amongst the fifty-eight competing countries. Malta scored an average of less than five hundred points in science education (Mullis, Martin, Foy, Kelly & Fishbein (2020). The alarming results stress the need for better engagement with science. Scientific literacy still remains the main global goal for science education (Holbrook & Ranikmae, 2009; Lestari, Setiawan & Siskander, 2020; National Curriculum Framework Malta, 2011).

1.4. No studies have yet focused on the social representations of teachers and children

Since the mid-twentieth century several attempts have been made to explore teachers and children' views, ideas and attitudes towards science and understanding of the Nature of Science. This interest was brought on by Wilson's first questionnaire introduced in 1956 to identify how children perform in nature of scientific knowledge. Since then, several research tools were developed including tests, questionnaires, inventories and the more recently qualitative questionnaires (Schwartz, Lederman & Abd-El-Khalick, 2012). However, several research instruments were questioned on their validity and to this day, after over sixty years of continuous work on NoS research instruments, development and validation of such instruments remains a challenging issue.

As well as the lack of suitable NoS instruments that could be used with children, at present there are further concerns when it comes to exploring teachers' and children' conceptions of NoS (Cofre et al., 2019; Lederman, 2013). There is a lack of representation of science as a collective endeavor. At present, children's and teachers' understanding of science is being explored using individual tests and methods- notably paper and pencil tests of interview situations (Lederman et al., 2002). Just as science is a collectiveendeavor, the way people think about science is constructed socially. Thus, it will be appropriate to look at how teachers and children construct their ideas about nature of scienceand build up shared meanings about science.

1.5. This study aims to explore the teachers' and children's social representations of Nature of Science

This study aims to examine the possibility of using a novel approach to elicit nature of science understandings from children (9-10 years old) and primary school teachers. The study uses age appropriate images and questions to stimulate discussion about nature of science in a more relaxed group situation. This has the advantage of discovering how social representations of Nature of science act as agencies of knowledge and stereotypes within society.

The study has been designed to use philosophical methods (through philosophical dialogue) to generate data, and to draw on nature of science ideas directly from philosophy of science. There are three reasons for exploring the social representations of Nature of Science. Social representations about Nature of Science have not yet been explored. Social representations will serve as a means to establish shared knowledge about nature of science amongst group members (Moliner & Abric, 2015) and thereby act to support children's and teachers' lay understanding of nature of science. The study shall thus look into the dynamics established between participants on nature of science as an object of knowledge. Often embedded in discourse, social representations refer to an organisation of views and values relating to a social object which in this case is science. Through dialogue about the social object (science), the framework shows a process of meaning making amongst participants, uncovering the often hidden assumptions that participants might have about science (Moscovici, 1988).

> *A social representation is a collective phenomenon pertaining to a community which is co-constructed by individuals in their daily talk and action.*
>
> Wagner et al., 1999 (p.2)

Secondly, as part of this study, participants are given space and voice to reflect on their own views on nature of science in response to the big ideas within philosophy of science (refer to chapter 2). There is no doubt that many representations of Nature of Science exist within society, this study aims to look at what knowledge foundations and psychological associations are involved in the formation of children and teachers' associations of science.

Thirdly, the study sets out to provide new shared insights into teachers' and primary school children's ideas about NoS to influence current practice within science education. The results of this research will be important for teachers to reflect on their shared understanding of science, and how such understanding can influence practice in science education, as well as for policy makers to identify what sort of understanding children and teachers have about Nature of Science to help with designing a curriculum for science education that reflects the needs of children.

The central aim study is to answer the following three research questions:

1. What are children's social representations of NoS?
2. What social representations do teachers' have about NoS?
3. Are there any differences between children's and teachers' social representations of science?

As well as providing a novel research tool through Wonder Wild, the social representations of children and teachers about NoS contribute to the ever-growing literature of NoS by parting ways from the more individual-oriented analysis and instead focus on the social constructivist orientation towards science.

The main design features of Wonder Wild are as follows:

- Underpinned by philosophy of science
- Friendly format to facilitate and prompt children's and teachers' engagement
- Not context-based to allow for participants to bring their own examples

- Simple text and jargon free
- Aims at being neutral
- Focusing exclusively on epistemological aspects of NoS rather than on skills/attitudes towards science

1.6. Establishing context: The current state of science education in Malta

Culture has a direct influence on the individuals' understanding of science (Mulkay, 2014). The cultural background can shape the worldview of the individuals and influences their understanding of certain concepts such as in the case of science. Education, beliefs and values are all inter-twinned in shaping our worldview.

Malta lies in the middle of the Mediterranean Sea just below Sicily and on top of the North African Coast. The Maltese Islands consist of the main island Malta, its sister Gozo and a number of small islands including Comino with a population of less than half a million in an area of 246 km2 overall . Maltese people have strong political ties and very strong Roman Catholic values.

Malta has been under the reign of Arabs, the Knights of St. John, the French and the English. The Maltese language and way of life has been influenced by these reigns, especially the English, who have left a big impact on the educational system in Malta in terms of curriculum, and the way that the educational system is structured.

Malta's basic education includes two years of Kindergarten for children between the ages of three and five and then six years of compulsory primary school for children between the ages of five and eleven. Once children finish primary school they are enrolled in secondary school for another five years of compulsory schooling up to the age of sixteen. In Malta there are three types of schools; state schools, church schools and independent schools. State schools are free for all children regardless of citizenship and faith. All books, resources and transport are paid by the government. State schools are currently co-education mixed, however secondary schools all around the island are separated by sex, excluding independent schools. Church schools are governed by the Catholic church, however there is an agreement between the Catholic church and the government that school fees are paid by the government.

However, parents are asked to give an annual donation to help with school costs. Parents have to pay school fees if they send their children to independent schools. All books, resources and transport have to be paid by the parents at an additional cost. As reported by the National Statistics Malta (2021), the majority of Maltese primary school children attend state school with a percentage of 57.1%. A consistent presence of church schools can be foundacross the island with an attendance of 29.4% of primary school children. Only 13.5% of children are enrolled in an independent (private) school across the island. The majority of children attending independent schools come from the northern area of Malta, with only 5%of children from the southern region attend a private independent school.

The Maltese linguistic scenario is directly related to its history and geography. Malta is a bilingual country with Maltese and English as the two dominant langauges spoken in Malta. Thus, children are expected to be fluent in both Maltese and English. Most instruction at school is carried out in Maltese, however many lessons within church and independent schools are instructed in English due to the number of foreigners, especially in the north and central part of Malta. Thus, many lessons take place in English with the exception of Maltese lessons. Maltese teachers are very accustomed to using linguistic code-switching. Linguistic code-switching refers to the process of alternating between two languages (e.g. Maltese and English). Although the use of code-switching is often done unintentionally, there are a number of reasons that it is used quite widely in Maltese schools such as to improve understanding for all children; when there are no Maltese words that can exactly replace the English words, or the Maltese words are not too familiar with the children; as well as to highlight some key words (Camilleri Grima, 2013). In science lessons code-switching is a very prominent tool.

TheEnglish language is the dominant language for science instruction in most schools, with science worksheets, science textbooks and science key words which refer to science equipment all written in English. Despite this, studies conducted by university professor Camilleri Grima (2013) in Maltese schools, show that code-switching is very dominant in science lessons especially for clarification purposes. The main reasons for this is that while science tests and resources are in English, Maltese children prefer to speak in Maltese and some children understand better when lessons are conducted in Maltese. The linguistic background of the participants was taken into consideration when developing the research tool and the interview/focus group schedules. While the interviews and focus groups will predominantly be carried out in English, code-switching might be used. The reason for this is to avoid marginalisation due to language abilities, as well as to enrich the understanding and discussions amongst children and teachers. Thus, Maltese transcripts will be presented alongside the English translation.

The Maltese educational system has two main educational documents. The National Minimum curriculum (NMC) or lately known as National Curriculum Framework for All (NCF) launched in 2013 and the Primary Syllabi. The NCF refers to the policy document on the actions, strategies and benchmarks for the evaluation and implementation of educational development. In relation to the current state of science education in Malta the document states

> *Locally, the present system is riddled with the effects of piecemeal strategies and decisions based on intuition rather than on empirical evidence that have accumulated throughout the years…While children are expected to develop fundamental scientific concepts, skills and attitudes during the primary school years, studies have identified a number [sic] issues and challenges for primary science within the international sphere… science education is two-fold: producing future scientists and providing the rest of citizens with a basic level of scientific literacy, historically science education is focused mainly on the first aim (p.9).*

The document also initiates a discussion on the importance of scientific literacy and its relevance to the Nature of Science with the credit that "most science curricula…end up being loaded with scientific knowledge, and limited time for experimentation and reflection, depriving children from understanding the process and nature of science." (National Minimum Framework, 2013, p.11)

The major concern in Malta was the Trends in International Mathematics and Science Survey (TIMSS) where Malta was placed in 30th place in Science Achievement amongst the other forty- nine EU countries. Following this review, science learning was revaluated with a vision statement outlining the purposes of science education; with the main goal being "to develop the scientific literacy of all learners...develops skills and ways of thinking that are important for decision-making and problem solving using an evidence-based approach…to provide a strong foundation for learners who wish to pursue a career in science and other science-related careers" (NMC, 2013, p.11)

Science learning starts during the early years of school by providing stimulating environments for the younger kindergarten and early primary children with tasks that encourage children to inquire, observe, stimulate their curiosity about the world around them and investigate how things work. The science syllabus is used for primary and secondary level of education.

The syllabus is a separate document published by the Directorate for Learning and Assessment Programmes (DLAP) and which provides general guidelines and tasks for science learning. The syllabus is mainly knowledge content- based, listing science topics to be studied by children along with the learning outcomes for each topic. The learning outcomes for science include understanding the world through enquiry; investigating phenomena and planning investigations; making predictions, drawing conclusions, communicating scientific knowledge and linking science to everyday life through the application of scientific knowledge. These all make part of the goal of attaining scientific literacy through 'working scientifically', recently being piloted as part of the new approach to scientific learning. Albeit there is reference to the processes of science such as those seen above, there is no reference to other aspects of nature of science including the aims of science and the products of science, to name a few. No reference to the different aspects of science can be identified in the curriculum.

Table 1.6 found below outlines the different age groups and how science education is applied in the Maltese context. The core science curriculum for form 1 and 2 offer the children a foundation for further studies in the different branches of science which include biology, chemistry and physics studies by children from Form 3 up to Form 5.

	Year Group	Age	Science Education
Kindergarten (in school)	Kindergarten 1	3-4 years	Understanding the World
Kindergarten (in school)	Kindergarten 2/ Pre-school	4-5 years	Understanding the World
Primary School	Year 1- Year 6	5-11 years	Core primary curriculum
Secondary School	Form 1- Form 2	11-13 years	Core science curriculum
Secondary School	Form 3- Form 5	13-16 years	Material science (i.e. chemistry) Physical science (i.e. physics) Life science (i.e. biology) (children have to choosetwo of the above options to study for 3 years of the end of secondary school)
Post-Secondary (College)	1st year 2nd Year	Non-compulsory	Children have the option to continue to study science at post-graduate level. Intermediate options (to choose one or two maximum) - physics, environmental science or biology Advanced level options (to choose one or two) – Physics, Biology and/or Chemistry
Tertiary Education (University)	N/A	Non-compulsory	N/A

Table 1.6: Science Education System in Malta

1.7. Synopsis of research design and methods

A qualitative study was chosen as a means to explore children and teachers' social representations of Nature of Science to capture evolving ideas and beliefs and enable deeper understanding using philosophical methods (Allan, 2020). The empirical research approach adopted for this study is one of a qualitative nature using philosophical methods.

To identify teachers' and children's social representations, focus groups and interviews with teachers and children in year 5 were deemed as appropriate methods. The focus group discussions were prompted using philosophical questions based on ideas from the philosophy of science, and the dialogue was facilitated in a philosophical way with probing for meaning and truth.

Philosophy is one critical component which underpins this study in both its theory and practice. For this reason, focus group and interview discussions were prompted using philosophical questions based on ideas from the philosophy of science, and the dialogue was facilitated in a philosophical way - probing for meaning and truth.

The aim of this study is thus to test an alternative approach and method by which it is possible for individuals (including primary school children) to share their understanding of and about nature of science. This is by giving them the opportunity to reflect on their own understanding of science by discussing their own thoughts and conceptions within their own social group (i.e. teachers with other teachers and groups of children in the same class). Dialogue about science is one way of exploring social representations amongst teachers and children.

This is the background against which Wonder Wild was developed. This study was focused on designing an instrument that will be useful for exploring children's and teachers' understanding of nature of science.

1.8. Overview

This thesis is composed of nine chapters. The literature review of this study is organised into three chapters; the first chapter within the literature review will be dedicated to the philosophy of science, this chapter will evaluate the ideas of Nature of Science (NoS) discussed by philosophers of science. This chapter lays out the theoretical dimensions of the research which has influenced the methods and research tool for this study. The second chapter within the literature (chapter 3) will explore NoS in science education, this chapter pertains to research instruments that have been used to study students' and teachers' understanding of NoS. Social representations as a framework for the research will be discussed in chapter four, the third and final chapter of the literature review. In this chapter a definition of social representations will be presented and social representations will be introduced as a framework for this study, stating the implications and acknowledging the difference in exploring social concepts between social representations and individual conceptions.

The fifth chapter in this dissertation will be concerned with the methods of this study. The sixth and seventh chapters present the findings of the research, focusing on the social representations of children and teachers respectively. Each section within these two chapters is dedicated to a social representation that has been identified in the study. Chapter eight will present the analysis of the findings from both teachers' and children's social representations. The social representations will be compared with previous findings, as well as the philosophical ideas demonstrated within philosophy of science in chapter two.

Finally, chapter nine will summarise on the findings of the study by focusing on three aspects; a). stating the implications and significance of the findings, b). discussing the limitations of this study, and c). addressing the implications for further research and practice in the teaching of NoS within science education. In the appendix, a copy of the eight Wonder Wild cards can be found.

Chapter 2

Literature Review: Philosophy of Science

The purpose of this chapter is to illustrate how philosophers, historians, and sociologists of science have constructed knowledge about how science works. Secondly, the aim of this chapter is to review ideas from the philosophy of science that may have influenced the way science is taught at school.

There has been great efforts by philosophers over centuries to understand what counts as science, what qualifies as a scientific theory, what scientific methods have in common and what the purpose of science is and ought to be – these can be considered as questions about the nature of science (NoS). This chapter will thus address questions on nature of science and the schools of thought that have tried to find answers to these longstanding questions on NoS.

The questions addressed in this chapter are concepts which have been discussed at length in the philosophy of science literature and scholarship, such as in Chalmers (2013) and Godfrey-Smith (2003). Chalmers (2013) and Godfrey-Smith (2003) are two important texts which have been used extensively in many philosophy of science in science education programmes. Following from these secondary sources, some references were then made from the original sources, such as from Popper, Kuhn and Freyerabend, and from other secondary sources that have analysed philosophical work. Due to the vast and research scholarship in this area, it is difficult to be inclusive. In consequence, this chapter refers only to the accounts of science that have received attention from western science, as those mentioned in Chalmers (2013) and Godfrey-Smith (2003).

2.1. How is scientific knowledge attained?

The epistemology of science- the study of the origin and process of knowledge has been subject to speculation for a number of centuries. This philosophical question on the attainment of scientific knowledge has led two schools of thought from the earlier 17^{th}, 18^{th}

and 19th centuries, rationalism and empiricism, to bring forth their own beliefs and ideas about the subject. Rationalists and empiricists are distinct in their views of how knowledge is acquired (Agbanusi, 2021).

As discussed in Agbanusi (2021), empiricists such as John Locke have stated that human knowledge, including scientific knowledge, is derived from the senses through experience. This school of thought is built on the premise that knowledge can only be deduced through experience alone. This belief was held by the philosophical movement of the logical positivism. Logical Positivism was mostly concerned with deriving knowledge which is true, since experience is the only certainty which the mind can attest. Positivism sought to understand the world through observations and how well these observations fit with experience (Kaboub, 2008; Caldwell, 2015). Similar of the notion that we learn through our experiences, empiricists are adamant that ideas are not innate and they develop in interaction with others and within the environments.

On the contrary, rationalists such as Descartes hold the belief that ideas are not necessarily learned through experience as the empiricists have stated (Agbanusi, 2021), with the belief that knowledge can be attained through reason alone, without any need for the senses (Daston, 2008). The difference of science in relation to philosophy was recognised through the understanding that philosophy applies reason and logic, whereas science is more interested in testing ideas through observations (Godfrey-Smith, 2013). This distinction was made by the Vienna circle in that philosophy never arrives to 'truth' considering that questions lead to more questions and thus philosophers were never able to ascertain their knowledge. Science deduces experience to a set of observations which determine the truth (Lloyd, 2012; Godfrey-Smith, 2013).

Aristotle as referred to in Lloyd (2012) argued that science is not only made of deductions but as a set of organised arguments of theories, and their explanations based on organisation of patterns. Scientific explanations were seen as a means to demonstrate a logical consequence of a specific circumstance. In light of this, the deductive reasoning involved only applied to what can be experienced, i.e. what can be observed and recorded. The authoritative and decisive role of the empiricist tradition, set the tone for science to be viewed as above all other forms of knowledge due to its certainty that science is logic justified through observations (Kaboub, 2008; Burnett, 2012).

Another one of the main challenges faced by empiricists was the issue of induction. The view that science is grounded in justified conclusions on the basis of observations, posed several questions about the generalisation of the inferential nature of these beliefs and the potentiality of such observations to predict behaviour in the future (Curd & Cover, 1998). Hume (1978) cites his earlier work (Hume, 1938) to argue that validation of induction cannot be guaranteed, as no observation can verify the truth of generalisations due to the limitations posed by small observational activities that scientists partake in. For example, depending on experience one could claim that all cows produce milk. Moreover such a generalisation could be tested through observations of cows to see whether the statement is true or not. However, generalisation of statements propose an issue with universality of knowledge claims and scepticism about acquiring truth about unobservable entities.

The Duhem-Quine thesis (Quine, 1953) argued against positivist ideologies of science as those proposed by empiricists. Contrary to what positivists believed, Quine argued that predictions cannot be deduced from a single hypothesis in isolation. The Duhem-Quine argument was that logical positivism neglected the psychological and social components of science. Problems with interrelated assumptions were not given any thought as to the role that these play in effecting the validity of theories and laws.

Another critical point made in relation to the Duhem-Quine thesis is the challenge of deducing which claim is responsible for a faulty prediction. The uncertainty brought about by this view as well as the limitations of observations, adds to the argument that not everything scientific is directly observable. This idea led to a decline in the empiricism and positivist views of science (Burnett, 2012). This encouraged other philosophers of science to express their own philosophies in relation to the epistemology and demarcation of Science. The idea that science is different from other forms of knowledge in that it is capable of demonstrating that knowledge, raises a very important point in the philosophy of Science: what exactly counts as scientific demonstration? Primarily this reflects the idea of observation and experimentation as two important aspects of science that demarcates science from other disciplines of knowledge.

2.2. What methods are used in science?

To understand the attainment of new knowledge, one needs to understand the methods by which new knowledge is produced. There seems to be the idea amongst the general public that there is such a thing as only one method in science, ‘the scientific method’ (Anderson & Hepburn, 2015). According to Anderson and Hepburn (2015), this popular scientific method is one which has been proposed by Bacon which was meant to replace the methods put forward by Aristotle that knowledge is derived from reason alone. As an empiricist, Bacon’s scientific method was built on the premise that scientific knowledge derives from experience and follows a simple logical order, starting with observation of natural phenomena which then leads to experimentation to test the observational phenomena (Bacon, 1861; Gower, 2012). Bacon added to the notion of Aristotle’s idea of science with his declaration that science does not deduce through argumentation, as arguments need to be tested (Anderson& Hepburn, 2015; Agbanusi, 2021).

Bacon was not the first person to critically engage with science through observation and experimentation but he was the first philosopher and scientist to explain the methods of inductive reasoning and set out what he called the ‘scientific method’.

> *Moreover, the works already known are due to chance and experiment rather than to sciences; for the sciences we now possess are merely systems for the nice ordering and setting forth of things already invented; not methods of invention or directions for new works*
>
> (Bacon, 1861, p.48)

As illustrated in Bacon’s argument taken from his book of Aphorisms (1861), he claimed that scientific knowledge is merely being derived through argument and authority rather than created through innovation. Bacon’s observations of the methods being used to make claims in science, encouraged his work titled ‘Novum Organum’ in which he proposes his scientific method. Bacon contended on evidence through experimentation and observation of the real world. Bacon rejected Aristotle’s conception of science as theoretical and rational and instead suggested an inductive method whereby proof and demonstrations are superior to scientific authority and subjective claims made from individual observations (Anderson & Hepburn, 2015; Agbanusi, 2021).

In his work on the scientific method (1861) Bacon argues that science is based on three fundamental steps; observation, deduction to explain theory of what has been observed and finally an experiment to test the truth of the theory in question. In this sense, Bacon proposed an empirical method to study and interpret natural phenomena in contrast with prior deductive methods, notably what has been used in empiricism (Chalmers, 2013; Gower, 2012).

Bacon's scientific method was attacked by several other philosophers including Kuhn, Lakatos and Freyerabend who objected to the universality, structure and logic of 'the scientific method'. Kuhn rejected the idea of a single method, as seen in his philosophical work on paradigms, Kuhn believed that anomalies (elements of scientific work which do not fit with previous scientific work) are evident as a result of change in time and space. He argued that these anomalies encourage a shift in science, with scientists exploring new processes and ideas in science. As a result he refuted the idea of the process suggested by Bacon and others such as Freyerabend and Lakatos followed suit (Chalmers, 2013).

Post Bacon, Galileo also questioned the need for authority for the search of truth and further extended on Bacon's view that the knowledge of truth can be gained through systematic experimentation (Galileo's experiment with gravity in the 1930s). Bacon's scientific method is often recognised as a set of rules and principles which govern science.

Albeit the popularity of Bacon's inductive method, a problem emerged with how scientists can justify theories which cannot be justified by induction alone. This challenged other philosophers, notably Popper who argued that justification is not an essential component of scientific work. Prevailing upon the tentative nature of scientific work and how justifying scientific work would lead to science becoming an authoritative force (Popper, 1953).

2.3. Is scientific knowledge falsifiable?

The problems faced by induction in science occupied the attention of Popper (1953). The inductive argument posed by the earlier works of Bacon inspired Popper to acknowledge that a scientific hypothesis should be refuted from observations in light of new evidence. He acknowledged that truth can never be claimed through successive testing but rather through a process of falsification (1953). In his work 'conjectures and refutations' he argued that science is a process of making claims and refuting these claims on the basis of new evidence (1953). He argued that the element which makes science different from other knowledge claims; such as the difference between claims made in Astrology and those made in Astronomy, is that scientific theories can be falsified and thus can be refuted in light of new contradictory evidence.

> *In so far as a scientific statement speaks about reality, it must be falsifiable: and in so far as it is not falsifiable, it does not speak about reality.*
>
> (Popper, 1963, p. 243)

Like previous understandings of science, falsifiability is understood to be guided by observation and it is through observation that theories are developed. Popper also argued about the nature of scientific theories in stating that theories are speculative and tentative, and developed through a process of trial and error (Chalmers, 2013).

Falsification has also challenged positivism in many ways including Popper's idea that scientists should be bold and creative with their conjectures and open for their theories to be rejected (Chalmers, 2013). In reality, scientists do provide criticism of each other's works through peer reviewing but this is seen to a lesser extent then what Popper is suggesting. This deductive approach to science has in so many ways been criticised due to its number of issues; such as that Popper's theory is not straightforward as it does not conclude why the theory is false and what could have been done to solve the problem with the theory (Chalmers, 2013; Derksen, 2019).

In recognition to the above issue with falsification, very little is learned through the process of falsifying knowledge claims, as no regard is given to the suggestions of how and why these theories are being falsified. The possibilities of the theories being falsified are infinite, so much so that it would be very difficult to know which theory is true until proven otherwise.

The tentative aspect of science is very much exposed in this view of science. The idea is that scientific theories are always developing with the addition of new evidence. As will be discussed in the next section, the concept of tentativeness is one that has been discussed by other philosophers such as Kuhn to highlight the developing nature of science.

2.4. How does science develop?

Several philosophers including Kuhn, Lakatos and Feyerabend have discussed in great depths the tentative aspect of science, as well as how scientific knowledge develops throughout the years (Chalmers, 2013). Tentativeness of science can be owed to the developing nature of science- in that science has the ability to evolve as a result of change in space and time.

Up until Kuhn (1970), science has been documented as series of individual discoveries (Chalmers, 2013; Kuhn, 1970). Kuhn (1970) had a different vision of how scientific knowledge develops, he argues that “perhaps science does not develop by the accumulation of individual discoveries and inventions” (p.2.)

Kuhn (1962) provides a contextualist view of science based on the development of objective knowledge and conformism within the research community. In sharp contrast to Popper’s theory of falsification, Kuhn (1970) discussed his theory of nature of science in his work ‘Structure of Scientific Revolutions’ in which he argued against individual claims and focused on a single framework with its interrelated assumptions, claims, beliefs and practices. His philosophy of science is a revolutionary one in which he proposes that scientists work in a paradigm that is made up of the beliefs, methods and laws of a particular point in time. The paradigm is an intellectual infrastructure that forms the worldview of the scientific research community during that point in time and guides scientists in their scientific activities, in the type of hypotheses that they form, the types of questions that they ask and how they go about conducting their research. Quoting Kuhn himself, he argues that knowledge “is always a formative ingredient of the beliefs espoused by a given scientific community at a given time" (1970, p. 4). Considering that worldviews are very much dependent on and reinforced through culture, socialisation, type of funding and professional development, Kuhn acknowledged the history of scientific disciplines and methodological assumptions of science. He argued that a paradigm remains constant before shifting when new theories are proposed which better explain scientific observations.

Kuhn suggested that scientific development doesn't take place as a result of accumulation of theories, and it does not progress linearly as earlier works suggest. He arguedthat new ideas materialise due to changes within the environment and the needs during thatcurrent time. Building on that, anomalies are thrown up when new questions emerge. Thesequestions challenge the norms of the current paradigm and as a result a paradigm shift takesplace. This starts with a period of pre-science (a period where scientific knowledge begins to be developed through theory) which then leads to a period of normal science (when a paradigm becomes established) and lastly where the 'science' is acknowledged and built on by solidifying the scientific 'organisation' or paradigm with other contributing scientific works (Kuhn, 1970).

Crisis is inevitable in science according to Kuhn (1970) and develops due to a number of anomalies in research that bring a shift in the focus of scientists' work. Kuhn acknowledges that such anomalies are assimilated to fit the current paradigm but if several anomalies do not fit the current paradigm, a scientific revolution takes place which changes the rules, assumptions and beliefs science; a process whereby previous scientific work is put into question and a new paradigm by which scientists' work, think and develop their theories is initiated. Kuhn (1970) refers to this process as being cyclic and thus, after a period of normal science new crisis and revolutions are bound to occur.

In response and opposition to Popper (1970), Kuhn resists the idea of falsifications of a paradigm and thus, he acknowledges that 'puzzles' that do not fit within the paradigm are not to be seen as 'falsifications' but rather as anomalies that can be either assimilated or can serve as challenges for a different 'worldview'. In response to this, Kuhn received criticism due to his essence that scientists work dogmatically to overexert the potential of a paradigm.

However, several issues have been brought up in recognition to Kuhn's idea of NoS; with the main challenge being that Kuhn does not explain how scientific activities and products are different from non-scientific ones. In response to this, Kuhn argued that the difference from say astrology and astronomy is that astronomy learns through its anomalies and failures whereas astrology does not. Another issue that was brought up with regards to Kuhn's theory of NoS is the justification of what makes a theory better than the other and by what criteria is this justification made. The de-emphasis on anomalies is felt in Kuhn's theory and no discussion has been made as to how previous paradigms have influenced new ones or what exactly determines which paradigm is better than the other. Despite the criteria for choosing paradigms, which Kuhn has established as being made up of prediction of success and ability to explain phenomena and coherency; choosing a paradigm is not a simple process that can be rationalised through the use of such criteria. Kuhn also faces other challenges with his view of paradigm shifts. One questionable assumption was that only one paradigm can exist at a time. Others have also criticised Kuhn about his assumption that progress can only be seen during the peak of normal science and that science revolution are not as dramatic as Kuhn makes them out to be. In fact, criticisms of Kuhn have offered points of reference that go against Kuhn's intense ideas of scientific revolution such as genetic mutilation and genetics.

2.5. Is there such a thing as scientific truth?

Inspired by Kuhn's theory of paradigms, Lakatos tried to free the difficulties in Popper's theory of falsification by attempting to apply Kuhn's theory of paradigms. Kuhn was unable to answer why a paradigm is more superior to the other which replaces it, and thus had to resort to the will of the authority in that decision. On the other hand, Lakatos proposed that a superior theory is based on novel predictions. He suggested that the worth of a theory is demonstrated by its ability to render explanations for phenomena.

Similarly to Kuhn's concepts of Science, Lakatos portrayed science as an activity within a framework, however unlike Kuhn he argued that the hard core of science is made up of scientific work including scientific theories and activities, whose worth is justified by the aptitude of how agreeable these theories are with each other in this ‘hard core’ of Science. Thus, in Lakatos’ terms, the hard core theories of science are rendered unfalsifiable in that they can only be further justified through further evidence and this then serves as a protective belt for the hard core theories of Science. He called this the research programme (1980).

> *There is no way of judging a theory but by assessing the number, faith and vocal energy of its supporters… truth lies in power*
>
> (Lakatos,1980, p.9)

The issue with Lakatos’s theory is that no rules were established for the elimination of theories. Unlike Popper whose theories were eliminated on the basis of falsification and Kuhn’s relativist approach to science that left the elimination of theories against the justifications of the people, Lakatos proposed that new theories are used to further demonstrate established theories. However he does not make reference to theories which do not fit the hard core of science.

Feyeraband further criticised Lakatos’s argument in which he argues that scientific work should display the same characteristics of physics for it to be considered scientific. Feyeraband points out that some characteristics of physics may be irrelevant and/or inappropriate for other scientific disciplines as different scientific disciplines operate differently according to the aims and methodologies that they are driven by.

2.6. Is there a universal way of doing science?

Opposed to previous theories of Nature of Science that focused mainly on the theoretical aspects of Science, Feyerabend focused primarily on the method of Science. His major contribution to NoS was his critical stance on universal method, stating that there is no such thing as a universal method in doing science. He has been very critical of Lakatos, especially with regard to Lakatos’ argument that for anything to be considered scientific, it should possess the same qualities and characteristics of physics. Lakatos identifies that having a high regard for Science can be a very dangerous dogma. With his refutation of the scientific method, he made no attempt to discuss the idea of observation and experimentation in Science. However, Feyeraband have discussed the full implications of the failures of scientific theories which other theorists like Popper and Kuhn have left out.

> *Science is essentially an anarchic enterprise: theoretical anarchism is more humanitarian and more likely to encourage progress than its law-and-order alternatives.*
>
> *(Feyerabend, 1993)*

Taking on a humanitarian attitude towards science, Feyerabend discusses how the institutionalisation of Science is very much inconsistent with the humanitarian attitudes. Feyerabend acknowledges that society pre-exists the individuals and thus, scientific work should acknowledge the subjective side of Science including the different sociological aspects that influence Science such as culture, funding, problems with society and societal needs amongst others. He argued that scientific theories can be genuinely tested when an alternative view of the phenomena in question is available. Feyeraband concludes that the idea of scientific method lacks rationality for Science and that there is no justification for scientific privilege over other forms of knowledge.

2.7. Is there a game of probability in science?

Bayes' theorem was proposed to revise probabilities based on the amount of scientific evidence available (Chalmers, 2013; Omlin & Reichert, 1999), stating that probabilities are heavily dependent on the amount of evidence. The greater the evidence, the greater the probability. The Bayesian approach established by Bayes (1702-1761) aims to describe how probabilities change in light of new evidence. It is grounded in the theory that knowledge is continuously progressing by adding new information to what has been already established, thus continuously updating the probability of likelihood for a hypothesis and increasing the chance that the new construction is closer to the hypothesis being true (Omlin & Reichert, 1999).

In science, the Bayesian method aims to describe how scientific evidence is assessed and how it should be assessed. The theory is based on subjective probability which refers to the probability of the likelihood that scientists' think the conjecture is true, rather than how likely the conjecture is true. This method or approach which is discussed in Strevens (2005) is based on two processes with four steps; the prior probability of the scientific theory to be considered true based on the scientists' background knowledge and the posterior predictive dissemination after new evidence emerges. This is the first step of the Bayesian method which is then followed by subtracting the probability and chance from the conditional probability. The probability for the given hypothesis is then updated with the introduction of new evidence. The second process is then introduced as the Bayesian Conditionalization which is found by multiplying the old probability by the factors involved. The factor would be the Bayesian multiplier. This would suggest the impact of evidence on the hypothesis. The two major distinctions are evidence with no hypothesis versus evidence with a hypothesis. This approach seeks to calculate the prior and posterior probabilities to show the assumptions that show a low probability.

As opposed to other scientific explanations to NoS, Bayesian approach to NoS is highly quantitative and focuses primarily on the method of science rather than as a demarcation between what science is and what it is not.

2.8. Is Scientific knowledge relative to time and space?

Relativism and Positivism have been known to be two extreme views when it comes to NoS. Relativism was a popular movement in the 1970s which was greatly advocated by Boyd (1973, 1983) due to the difficulties with Positivism. Relativists argue that science goes beyond observation; an argument against Popper's and Kuhn's ideologies and processes of science. The relativists' attitude reflects the necessity of science to be a progressive entity within society.Relativists agree that science has been able to predict eventualities successfully because it isprogressive in nature and is abductive in reasoning (ability to predict instances which may betrue based on inferences). This contrasts greatly with other views of NoS where inductive or deductive reasoning believed to be applied in science. One of the most distinctive ideologiesof relativism is that all worldviews are given the same importance and are all considered equally valid within society. This stems from the philosophy that truth is only relative to the individual. Individuals are said to have different conventions and frameworks in relation to their social contexts (i.e. their beliefs, background, culture, history, etc.) There seems to be adependency of phenomena on some factors when it comes to seeking truth , however thereare a number of independent variables such as the ones in the social context (Kusch, 2020). These social contexts or conceptual frameworks of the individuals all come to play in the justification of truth. Truth is seen as perspectival and thus reality exists only in the eye of thebeholder. Notwithstanding, relativism claims that truth and the justification of truth exist in plurality (Kusch, 2020).

Duhem's thesis (1861-1926) adds justification to the philosophy of relativism in stating that empirical evidence alone is not sufficient to ground scientific theory. The thesis is used to bring to the forefront the acknowledgment that the social contexts (including conceptual frameworks) are not a natural entity and thus, subjectivity is a manifestation that cannot be avoided in the search for knowledge and the truth. The pluralist view is thus appreciated in terms of the diversity and the tolerance that this effectuates.

The philosophy of science is a historical one in which different views of NoS throughout the years have been discussed and criticised in terms of methodological aspects, the ontology of science, development of science and the demarcation of science. What constitutes as 'Natureof Science' has been greatly debated amongst scholars from different disciplines, due to the acknowledgement of various ideas and beliefs that come to play in relation to science as a discipline.

As can be seen by this recount, the worldviews of science are are progressive in nature and have accommodated the many different views, which under careful consideration can be seen as being influential on each other. The philosophy of science aims to captures all the distinctive ideas that led to the way by which we characterise science today. The views of Science have become a pluralist milieu, illustrating the diversity in philosophies pertaining toNoS.

This section provided a historical and philosophical account of nature of Science. It illustrated that there is no universal view of science. "No general account of science and scientific method to be had that applies to all sciences at all historical stages in their development" (Chalmers, 1999, p. 247). The fact that there is limited consensus amongst philosophers means that there is unlikely to be consensus amongst the general public, so to study NoS, weneed to be open to different responses and to how these views can be evaluated.

The philosophical perspectives highlighted in this chapter challenge and incorporate the characteristics of science discussed in most nature of science education documents. For this reason, the statements /characteristics of science mentioned in this chapter informed the resource used in this study to engage participants with various philosophical perspectives about nature of science The approach taken here aims to question and analyse the assumptions and arguments that underlie scientific knowledge.

Chapter 3

Nature of Science in Science Education

The previous chapter outlined some of the key debates in nature of science (NoS); what scientific knowledge is, how it can be tested, and how we can be sure about scientific knowledge claims and to what extent. These philosophical ideas challenged educational scholars to identify some key concepts that are worthy to frame science as a school subject.

Moreover, the debate between philosophers of science about the nature of science is mirrored in science education. For this reason, this chapter will first introduce different definitions of NoS by science educators and how such definitions influence science education practice. Secondly, current research on teachers' and children's concepts of NoS will be evaluated. Particular attention will be paid to current assessments tools being used in research with children and teachers on NoS. This chapter will also include an analysis of the methods that have been used to understand children's and teachers' understanding of NoS and their attitudes to science. In this chapter, the aim is to understand i). what is known about NoS in science education; and ii). how it is known.

3.1. Definition of Nature of Science in science education

From reviewing the literature on nature of science it is evident that different definitions of nature of science serve different functions in science education. The multi-dimensional aspect of nature of science brings forth many different views about characteristics and aspects of science (Chalmers, 2013). Scholars have claimed that there is no universal nature of science, stating that a series of characteristics of which are relevant to science does not accurately portray science and neither does it confirm what is to be considered as nature of science (Herron, 1969, Ecevit, Yalaki & Kingir, 2018). For example, Ecevit et al. (2018) view the plurality and complexity of NoS as *"…ever changing, developing, multi-dimensional and complex phenomena that to agree on a definition of science is very difficult"* (p.155*).*

Other scholars within the field of science education have also stated their thoughts on this dilemma, for example, Duschl (1994) states there is no such thing as consensus when it comes to nature of science. This argument has been backed up by Lederman (1992) who states that NoS is never stable, it changes with time and context as was seen from the abundance of the views presented earlier in this chapter.

Scholars within science education itself have not reached an agreement about the best way to characterise NoS. As a matter of fact, four notable scholars in the field of NoS within science education; Clough (2006, 2007), Allchin (2011) McComas (2006), Schwartz, Lederman and Abd-El-Khalick (2012) have presented conflicting views about NoS (as detailed in Table 3.1), making it challenging to incorporate in school science, where science tends to have very clearly defined working outcomes.

In relation to the definitions mentioned above, there seems to be an ongoing argument about which definition of NoS should be targeted in schools. However, there is still the question of whether NoS can be explicitly or implicitly taught and whether it should be taught as knowledge or in terms of scientific skills. Allchin (2011, 2012) for instance argues that NoS can be used as a means to critically engage children in effectively developing a set of skills necessary for the development and enhancement of children's scientific literacy. He argues that "there is yet no evidence that mere recall or comprehension of such NoS tenets is adequate for applying them effectively in context" stating that "NOS understanding needs to be functional, not declarative" (Allchin, 2011, p. 523). He presents his 'whole science' approach for which he argues that students should gain a "functional understanding of scientific practice and its relevance to decision-making" (Allchin, 2011, p.519).

Lederman (2007) and Schwartz, Lederman and Abd-El-Khalick (2012) on the other hand, argue that despite the similarities between NOS and scientific inquiry and the importance of both, the two items should be distinguished. In response to Allchin (2011), Schwartz et al. (2012) argue that "research demonstrates that doing something does not equate with or entail developing knowledge of underlying epistemological bases" (p. 686).

As cited in Schwartz et al. (2012) prior to the 1990s it was common for NoS knowledge to be misidentified with scientific attitudes and skills as a result of the common belief that if children were involved and practicing science, they would be acquiring knowledge about NoS. This notion was likened to Allchin's view which relates NoS to something that students can do in practice. Schwartz et al. (2012) argue that NoS should encapsulate the underpinnings of science; the principles which govern scientific work, thus it should not by any means be seen as a skill, and not be equated as such. The work produced in this study underpins Schwartz et al.'s (2012) definition of NoS, with the argument that the philosophical principles and ideas are a keen component of NoS that encourages pupils to engage in discussions about science and its processes.

The meaning ascribed to NoS has implications for the type of NoS to be included in science as a school subject. The debate between Allchin (2011) and Schwartz, Bell and Lederman (2012) regarding their different approach to NoS, and thus their different approach to assessing NoS understandings, demonstrates this. Schwartz et al. (2012) state that school science goes beyond the attainment of scientific skills such as decision-making. It is stated that while such skills might be attained with the understanding of NoS, the attainment of scientific skills are not definite or justified with the learning of NoS (Schwartz et al., 2012). They propose that NoS is the foundation of knowledge with respect to how science justifies its knowledge claims. As well as its reliability and validity as distinct from other disciplines. It is very interesting to note the value that different scholars place on the criteria of what constitutes as NoS; Baker (2000) defines NoS as being a set of characteristics that define science. Whereas Wuerston (2006) recognises NoS as being defined by the rules of the process of science, with the latter showing a more disciplined view of science. More recent definitions of NoS have been proposed by Erduran and Dagher (2014) describing NoS as different aspects of science including the cognitive, social and epistemic aspects of science.

The diverse views of NoS have all stressed the need for NoS be an integral aspect of the curriculum of science education (McComas, 2006). Science education is intended to engage the public (i.e. school children) in the understanding of the world. Marincola (2006) claims that science education is well suited to young curious learners to actively engage them in scientific enquiry and critical thinking. Scientific enquiry and critical thinking are two skills which are often taken for granted in science education (Rudolph, 2000). Teaching nature of science is a way to ensure that the public understands the inner workings of the processes of science and to apply context to the content studies in science. Science has served as an intermediary between science as a discipline and an endeavour in society (Rudolph, 2000). Different groups or individuals within society will have a different way of understanding what science is depending on their interaction with science (i.e. what we read and understand).

Abd-El-Khalick, Bell and Lederman (1998) state that *"NoS is a safeguard against dogmatism, necessary for making decisions regarding scientifically related societal issues, or that it reinforces the learning of science process skills"* (p. 437).

3.2. Aspects and characteristics of science emphasised in science education

Many scholars such as McComas (2017), Olson (2018), Alters (1997), Abd-El-Khalick (1998), Lederman, Schwartz and Bell (2002), and Hottecke and Allchin (2020) were concerned about the sort of 'nature of science' that would be ideal to represent science to school children. In reviewing the literature of nature of science within the last two decades, some agreements amongst many western scholars of science education was noted. This list of characteristics that most scholars within science education agreed on is made of seven key components; 1). Theories and scientific laws, 2). Observation and inference, 3). Subjectivity of science, 4). Creativity in science, 5).Tentativeness of scientific knowledge, 6). Social and cultural embeddedness of science and, 7). Scientific methods. Several scholars suchas Abd-El-Khalick (1998) and Lederman et al. (2002) have contributed to these aspects of science by suggesting a set of statements which are deemed appropriate for science education. Abd-El-Khalick (1998) suggested that:

- There is no universal method of doing science
- Science is an attempt to understand natural phenomena
- There is no hierarchy of knowledge between laws and theories
- Observations are theory-laden
- Science is socially and culturally embedded
- An existing relationship between science and technology (i.e. technology is not just an application of science but also drives scientific research)
- Science involves creativity and imagination
- Science is heavily reliant on observation, rationalisation and experimentation

Similarly, Lederman et al. (2002) proposed that these statements about science should be supported in schools for children to have an appropriate understanding of science. These include that science is heavily based on both observation and inference, socially and culturally embedded, lacks universality in its method, empirically based, tentative, creative and subjective.

Although the perspectives from the philosophy of science have been instrumental for research in NoS education and have shaped numerous research tools for NoS, there has been limited exploration into how children and their teachers perceive these philosophical concepts and develop their own ideas about science.

Nevertheless, there seems to some underpinnings of philosophy of science evident in the proposed statements about science. Table 3.2 below is an illustration of the similarities between the concepts of science that has perturbed philosophers of science over the years (see chapter 2) and the 'consensus' statements presented for NoS in science education.

Philosophy of science concepts	**Statements on NoS for science education**
Scientific knowledge is built on sense experience	Subjectivity, science is theory-laden
Science is discovered from experimentations and observations	Science is rational and based on experimentation and observation
Science can be falsified	Scientific knowledge is tentative
Science develops through paradigm shifts	Social and cultural embeddedness of science
Scientific truth lies in power	Theories and laws
Science is not confined to one method	There is no universal method of doing science
Science is a series of predictions	-
Scientific knowledge is relative to time and space	Social and cultural embeddedness of science

Table 3.2. Comparison of philosophy of science concepts with NoS concepts for science education

As can be seen from the table, there are several overlapping concepts between philosophy of science and the statements about NoS presented for science education. The social and cultural embeddedness that was recognised by philosophers such as Kuhn, is an acknowledged characteristic for science education as discussed in Lederman et al. (2002) and

Abd-El-Khlalick (1998). The culture and social embeddedness of science is heavily reliant on the idea that scientists work in a paradigm that is predisposed by the type of culture and society in that given point in time (Kuhn, 1970). This aspect of Science was also recognised by Lakatos (1980) and his similar disposition of Kuhn's theory with his idea of the research programmes. With the difference that paradigms are progressive in light of new evidence, whereas Lakatos and Musgrave (1970) argue that research paradigms are degenerative in that some scientific theories are in 'protective belt', protected with the prospect that that they can be progressive in the future. The tentativeness aspect of science can be traced to the influence of Popper with his theory of falsification and further congealed by Kuhn with his notion that paradigms are tentative and progressive in nature. Relativists such as Boyd (1983) have also outlined this idea and consider science as progressive due the ability that science can change in light of new evidence.

Both Lederman et al. (2002) and Abd-El-Khalick (1998) have also recognised the lack of universality in scientific methods. This idea can be traced back to Bacon (2000) and Feyerabend (1993) and the debate as to whether there are principles by which science can be used to make knowledge claims. The distinction between observation and inference (i.e. what can be observed through sense experience and what is inferred from observation is one concept which has made its way to the statements on science for science education. This concept is also one which is being targeted in schools (Finson, 2010; Sarıtaş, Özcan, & Adúriz-Bravo, 2021). Inference and observation as two scientific methods is one which has challenged many philosophers such as Hume (Traiger, 2018), Rosenkrantz (2012), Salmon (2017).

All these views have be greatly challenged throughout the years. Concepts such as the inferential nature of scientific claims have for example been discussed to a great extent in terms of theories and laws on forces, as well as atoms, and notably Einstein's theory of relativity. The idea of creativity and imagination as important characteristics of science can also be drawn to Popper (1953) and Kuhn (1970) and their beliefs that scientists are creative enough to come up with intelligent hypothesis based on their openness to study the natural world objectively and to be open to criticism on their work. Throughout the historical account of NoS, experimentation and observation are two distinct methods of science which have been commonly referred to (Millar, 2012; DeBoer, 2019).

3.3. How is Nature of Science addressed in science education?

Numerous theories and policy documents have addressed the need for NoS in the teaching and learning of science in schools across different countries, including Malta (National Curriculum Framework, 2011; Olson, 2018; McComas & Nouri, 2016; McComas, 2019; Matthews, 2019; Department for Education, 2013; Dewey, 1916; National Science Teachers Association, 2022).

The vision statement for science presented as part of the National Curriculum Framework for Malta (2011), has expressed the need for children to become active learners in the science classroom and acknowledge the processes and characteristics of science. The framework has introduced three strands for science education, one of which is dedicated to 'Core Science'. In the vision statement, Core Science is aimed at

> *Help[ing] students attain scientific literacy by providing them with a balanced view of science covering a range of concepts, principles, theories and methods of investigation. The content will be organised in themes bringing together knowledge from different areas to show the coherence of science and the need to use concepts from different sciences to understand natural phenomena and to solve everyday problems (p.12).*

3.3.1. How NoS relates to scientific inquiry and processes of science

Current instruction and policy documents are designed to improve science education and to enhance scientific literacy amongst learners (Lederman, Lederman & Antink, 2013). Reflection of skills and scientific processes are related to the construction of scientific literacy(Lederman et al., 2013). Philosopher of education John Dewey, has expressed a number of recommendations for science education to be active in society (1897). In his pedagogical creed, he reports the need for young learners to inquire about the social world and actively learn through experience (1897). He wrote several philosophical texts such as Logic: The Theory of Inquiry (1938a) in which he reflected on the different stages of thought relevant for the development of critical thinking in education. In his work, Dewey argues on the need for inquiry to serve as reflection or thought into the way children learn science, and stressed the importance of the scientific method to reflect the epistemic authority of science. Scientific inquiry is one way of developing scientific knowledge by taking into consideration the different processes required to be able to do science, such as critical reasoning and scientific reasoning (Lederman, Lederman & Antink, 2013).

Dewey's philosophy has underpinned many pedagogies throughout the years, such as problem-based learning (Kolbaek, 2018), inquiry-based learning (Herman & Pinard, 2015; Bogar, 2019) and dialogical teaching methods (Kolstø,2018) and continue to be an influence for a number of studies in Malta where science education is moving towards inquiry-based teaching and learning (Attard, 2019; Buhagiar & Sammut (2018, 2020). Dewey's contributions continue to be influential in science education with his ideas on the process of inquiry as a requisite of science learning (Karaşahinoğlu Fackler, 2020).

Dewey has argued in favour of the scientific method for use in schools, stressing on the epistemic authority of science. Science lessons built around inquiry are initiated by a topic of enquiry constructed from sense experience (usually a source of everyday experience), such as 'Why is the soil brown?' which then instigates the children to carry out investigations to answer their enquiry (Constantinou, Tsivitanidou & Rybska, 2018).

Science as enquiry is both a Deweyian and Schwab perspective (Kelly, 2014). Dewey has ratified the importance of acknowledging science as enquiry (Dewey, 1938; Crawford, 2014), whilst Schwab has suggested the activities of science as a source of enquiry (Schwab, 1962; Crawford, 2014; Kelly, 2014). Schwab's perspective of science continued to propose a public awareness of the characteristics of scientific enquiry (Rudolph, 2001). Both Dewey and Schwab have put emphasis on young learners attaining a general competence of enquiry, this have influenced policy makers in several countries, including Malta and England to acknowledge enquiry as in important force in science education (Gatt & Armeni, 2014; Zerafa & Gatt, 2014).

The skills learned through the process of enquiry in schools are endorsed by policy makers and curriculum developers as they are directly linked to the specifications of a scientifically literate citizens (National Curriculum Framework, 2011; Zerafa & Gatt, 2014). Scientific inquiry, or the british known term 'scientific enquiry' is a functional term in the English educational system, predominantly in policy and reform documents (Murphy & Beggs, 2005; Holman, 2006; McNerney & Hall, 2017). This term made its appearance with the current pressures received for children to acknowledge the scientific processes together with the content that they learn in school science (Holman, 2006). The National Curriculum in England has referred to several features relating to scientific enquiry which describes the processes and skills of science learning (DFE, 2013). This term has now been replaced with 'working scientifically', a term which is being used in the curriculum in England to refer to emphasises the learning of scientific processes. The term refers to children engaging in "the nature, processes and methods of Science" (DFE, 2013, P.4) by giving children the opportunity to plan enquiries, use scientific equipment, ask questions, observe and measure, identify and record information, and communicate their findings (DFE, 2013). It generally refers to the critical engagement that children have with science, helping them to develop scientific literacy and helping in contributing to greater awareness and acknowledgement of the structures and systems of science. Several curriculums (including U.K. and Australia) have differentiated hands-on experience and 'working scientifically' very well, however research has established that it is commonly perceived that thinking and working scientifically is equal to giving children hands-on experience in the science classrooms (Smith, 2016).

3.3.2. How NoS relates to working scientifically

In contrast to the term 'scientific enquiry' which is mainly focused on method, 'Working scientifically' is mostly skills-based in nature. It lacks a few characteristics of scientific enquiry in that it does not specialise in reflexive thought and scientific reasoning as in the case of scientific enquiry, with scientific enquiry having equivalence to rationality and reflexive reasoning skills (Westbrook, 1991). Working scientifically is so far acknowledged in very few studies. The National curriculum in England (2013) have acknowledged the critical benefit for 'working scientifically'. They have used the term as a statutory guideline for all children in relation to science teaching and learning. The English primary curriculum has established three aims for working scientifically, these are:

- To develop scientific knowledge and conceptual understanding through specific disciplines of biology, chemistry and physics

- To develop understanding of the nature, processes and methods of science through different types of science enquires that help them to answer scientific questions about the world around them
- To ensure that children are equipped with the scientific knowledge required to understand the uses and implications of Science, today and for the future.

(National Curriculum England, 2013)

The curriculum cites several aspects such as pattern seeking, exploring and applying models which are all different features of the scientific processes within nature of science. Hence, 'working scientifically' is only one integral aspect of nature of science and albeit its necessity for the learning of science, not all aspects of nature of science are being explored such as the philosophical and historical aspects of science and how science justifies its knowledge claims.

On the other hand, the Maltese national minimum curriculum does not refer to nature of science directly, nor do they refer to 'scientific enquiry' as a term (DfQE, 2022). However aspects of nature of science through enquiry have been of great impact (Gatt & Armeni, 2014). In Malta, inquiry-based learning is highly advocated as an important pedagogical approach for use in primary schools. The curriculum vision of Malta is highly influenced from Dewey and Schwab's ideologies of school science with many educational researchers and initial teacher trainers endorsing inquiry-based learning as a pedagogical approach to teaching science.

However, in the Maltese science syllabus (DfQE, 2022) reference is made to the understanding of the scientific community and the understanding of scientific knowledge as the ultimate aim for achieving scientific literacy and appreciation for further science education. It can be noted that educational documents which are consistent with Allchin's (2011) perspective due to the importance placed on scientific skills and activities as central goals for science learning.

The empirical research articles surrounding NoS in science education have provided various conceptualisations of this subject area. Most of the research conducted in this field refers to principle tenets of NoS proposed by Lederman (1998) and Abd-El-Khalick (1998) as the basis of their study. These tenets have formed the ‘consensus view’ which is now considered outdated in its characterisation, due to the philosophical and theoretical perspectives of science (Erduran, 2014; Dagher & Erduran, 2016). A nuanced view of NoS has been proposed in the form of a interdisciplinary approach which takes into consideration the philosophy of science, the socio-political studies on science, linguistics and anthropology (Erduran, 2014).

For instance, Piliouras, Plakitsi & Nasis (2015) talk about their concept of NoS as being the ideas about science and the values that it communicates in terms of its practices and presentations. In contrast to this, Carey, Evans, Honda, Jay and Unger (1989), conceptualise NoS as being behind the process skills and the mechanics of doing science. Others such as Mellado (1997) discuss NoS in terms of the two distinctive views; Relativism and Positivism, which are continually questioned and discussed in the philosophy of science (refer back to chapter two). It is interesting to note that Erduran (2014) and Dagher and Erduran (2016) offers a more conceptual understanding of NoS with the belief that there is no one perspective of NoS and that the meaning of NoS is constructed on the basis of different interpretations of how people view science.

This study shall take philosophy of science to be a critical component of nature of science. For this reason, the nature of science presented in this study has been heavily influenced from Erduran (2014) and Dagher and Erduran (2016).

3.4. What research instruments have been used to gain access into children’s and teachers’ understanding of Nature of Science?

With increasing interest in NoS for science education, several instruments were developed to access understanding of nature of science of both children (primary and secondary), as well as teachers. Following from the first instrument created by Wilson (1956), several attempts have been made to create instruments which present an appropriate view of NoS and which aim to explore valid and reliable accounts of participants understanding of NoS (Matthews, 2014). For this reason, instruments were developed with the scholars’ own criteria for NoS in science education.

This section will explore the methods used in the elicitation and/or assessment of children's and teachers' views of NoS. Furthermore, this section will address methodological implications of children's and teachers' conceptions of NoS and how these have influenced the type of results that are currently known as children's conceptions of NoS. Students' and teachers' conceptions of NoS will follow after this section.

There has been a great shift in research instruments for NoS since the mid-twentieth century when the first instrument was designed by Wilson in 1954. By way of advancement, in the last twenty years, there has been little progress with characterising a view of NoS which is appropriate for science education and one which can be used to assess children's and teachers' own understanding of nature of science. The 'Views of Nature Of Science questionnaire' (VNOS) designed by Schwartz and Lederman (2002) is one instrument which has gained popularity since its time of development. This instrument has been developed with Lederman's own criteria and characteristics of science which have been established in 1998 (refer to section 3.1.) and has been used extensively in several studies as will be discussed in the following sections.

As Table 3.4 below illustrates, research instruments on NoS can be categorised into questionnaires, inventories, tests, scales and qualitative/semi-qualitative research tools. Early research tools were mostly paper and pencil tests. Quantitative tools were the most popular, especially in the 1960s and 1970s with tests being the preferred research instrument to measuring students' skills and understanding when it comes to science and NoS (Abd-El-Khalick, 2014). The table below illustrates Abd-El-Khalick's (2014) review of the research instruments developed and used to measure understanding of nature of science. Other instruments which have not been illustrated below are ones which have not been serviceable from their time of development.

Research tool	Author
Questionnaires	
Science attitude questionnaire	Wilson, 1954
Views on science-technology-society (VOST)	Hillis, 1975
Nature of science survey	Lederman & O'Malley, 1990
Inventories	
Inventory of science attitudes, interests and appreciations	Swan, 1966
Science Process Inventory (SPI)	Welch, 1966
Wisconsin Inventory of Science Processes (WISP)	Literacy Research Center, 1967
Science Attitude Inventory (SAI)	Moore & Sutman, 1970
Science Inventory (SI)	Hungerford & Welding, 1974
Tests	
Facts about science test (FAST)	Stice, 1958
Test on understanding science (TOUS)	Cooley & Klopfer, 1961
Processes of science test	BSCS, 1962
Tests on the social aspects of science (TSAS)	Korth, 1969
Nature of Science Test (NOST)	Billeh & Hasan (1975)
Views of Science Test (VOST)	Hillis, 1975
Test of science-related attitudes (TOSRA)	Fraser, 1978
Test of enquiry skills (TOES)	Fraser, 1980
Conception of scientific theories test (COST)	Cotham & Smith, 1981
Scales	
Science attitude scale	Allen, 1959
Science support scale	Schwirian, 1968
Nature of Science Scale (NOSS)	Kimball, 1968
Nature of Scientific Knowledge Scale (NSKS)	Rubba, 1976
Modified Nature of Scientific Knowledge Scale (MNSKS)	Meichtry, 1992
Semi-qualitative/qualitative	
Views of Nature Of Science (VNOS)	Schwartz & Lederman, 2002
Critical Incidents	Nott & Wellington, 1995

Table 3.4. Instruments for NoS research

Wilson's Science Attitude questionnaire (1954), was the first instrument that was used to address the growing concerns about students' relationship and attitudes to science. However, due to poor content validity (Blalock et al., 2008), the questionnaire did not reach popularity and was only used with a small sample of students. Despite this, Wilson's questionnaire encouraged other scholars to design their own instruments.

The introduction of Wilson's questionnaire encouraged other scholars to construct research instruments as a means to assess three areas of science (Abd-El-Khalick, 2014);

i. abilities and skills in terms of understanding of the process of science,
ii. science as an institution (no reference to the epistemological characteristics of science),
iii. attitudes to science and scientists.

Several attempts were made to design instruments for exploring the above areas. However, very few actually managed to be sampled by participants (Abd-El-Khalick, 2014). One of the main challenges that was prominent in designing instruments for NoS was poor content validity. In fact, successive instruments were questioned on their validity, including the Science Attitude Scale developed by Allen in 1959, Facts about Science Test (Stice, 1958) and Test of Enquiry Skills (Fraser, 1980). There seemed to be a big challenge to identify the sort of aspects of science which are to be addressed towards a meaningful understanding of NoS.

Assessment of children and teachers' conceptualisations of NoS have been mostly quantitative prior to Lederman's (1998) and Abd-EL-Khalick's (1998) proposed 'tenets' of science and have mostly used convergent paper and pencil tests to measure students' conceptions and beliefs. After this period, most studies then took a mixed-method approach due to the several critiques that came with quantitative studies which will be discussed later in this section (Blalock et al., 2008).

These tests aimed to a). test the participants' understanding of science (Cooley & Klopfer, 1961), b). test nature of science (Billeh & Hasan, 1975) and c). the different conceptions of scientific theories (Cotham & Smith, 1981). Despite the popularity of these tests, their validity has been questioned due to the forced and limited responses that these questionnaires permit. One of the main reasons that decreased their validity is the level of ambiguity of these tests. Such tests involve Likert scales and multiple choice questions which might create unavoidable bias due to forced choice responses. The validity of these questionnaires such as Hillis' questionnaire (1975), and Lederman and O'Malley (1990), might also be questioned since the statements within the questionnaire might provide different interpretations depending on the expertise and understanding of the participants for example when comparing young children and older secondary school students, or teachers and children. Empirical research has documented that participants' characteristics as well as the characteristics of the questions affects reliability (Schwartz & Hippler, 1997). The motivation, difficulty of the questions in the questionnaires and children's cognitive ability to answer the questionnaire, all contribute the kind of responses that the children will generate for the study (Borgers & Hox, 2000).

Due to the criticisms that these tests have had, especially with regard to ambiguity and validity, Koerber, Osterhaus and Sodian (2014) investigated the use of these tests when administered with primary school children about their different understandings of NoS. For their study they divided sixty-eight third grade student participants from four different classes into two groups; giving the first group a set of multiple choice questions with open-ended questions based on scenarios; and the second group were given the same multiple choice questions. The first group also had a follow-up interview for children to explain their answers. Same as other quantitative studies, answers were coded as being naïve, intermediate and advanced. The findings suggest that the uncertainty about the requirements of open-ended questions together with difficulties in verbal abilities when addressing young children can make it difficult to draw conclusions about children's understanding of NoS. This suggests that the abstract nature of NoS together with the difficulty that young children experience in order to express themselves make paper and pencil tests not just unreliable source of data collection but also not age appropriate for use with younger school children, highlighting the need for more age appropriate NoS instruments.

The lack of reliability and validity when using such tests have led way to the propositions of other instruments that can be used to measure NoS views of children. The 'Test of Science Related Attitudes' (TOSRA) is an instrument which aims to measure pupils' attitudes towards science based on seven main categories; social implications of science, attitudes towards scientists, how scientific attitudes are adopted, attitudes towards scientific inquiry, enjoyment of science education, voluntary interest in science and interest in following scientific careers (Fraser, 1978; Welch, 2010). Additionally, the 'Nature of Science Instrument' (NOSI), a twenty-eight item instrument developed by Hacieminoglu (2014) to measure students' understanding of NoS, has been used by Toma et al. (2019) with one hundred and forty nine students primary to middle school students from seven different schools to understand children's attitudes to science.

Correlative studies such as the study by Yalaki (2019) aimed at finding a correlation between the effects of gender, cultural background and age and the influence that these factors have on the attitudes and views towards nature of science, is one popular use of quantative studies used nowadays. While this instrument has also been used with middle school students, an adaptation in the form of NOSI-E was developed for use with younger primary schoolstudents. However, there are limitations to using questionnaires such as NOSI-E with children.Koerber et al. (2014) and Lederman et al. (2002) identified that the appropriateness of language, such the understanding of the statements and wording used in the questionnaire could be limiting factors. So is the uncertainty of statements and the answers that they generate. It is also not very clear in such studies whether there is a lack of understanding in relation to NoS, or there is a lack of understanding in terms of the language used to explain the statements in the questionnaire, this is likely to be particularly acute for primary school children (Koerber et al, 2014; Lederman et al., 2002; Abd-El-Khalick, 2014).

While the vast majority of instruments were constructed around the mid-twentieth century, as can be seen from the table above, the introduction of the 'consensus view of science' brought about changes to assessment tools for NoS. Scholars such as Lederman et al. (2003), were interested in matching teachers' and children's views of NoS to the consensus list as a means to identify whether participants' views about NoS were informed or misinformed. This led to the new instrument 'Views of Nature Of Science' (VNOS). The VNOS is still one of the the most popular instrument tool as recorded in recent citations to this date.

In response to the critique given by Abd-El-Khalick et al. (2002), a mixed method instrument proposed by Lederman et al. (2002) was developed. The first original form of this instrument was VNOS- Form A, 'Views of Nature of Science Questionnaire' (VNOS). The questionnaire was aimed to elicit and clarify the learners' views of NoS with seven open-ended questions together with follow-up interviews to justify the responses of the seven item questionnaire. The VNOS proposed by Lederman (2002) is based on and limited to tenets of NoS proposed by Lederman and his colleagues (Lederman et al., 1998). These include several NoS aspects such as tentativeness, social and cultural embeddedness and subjectivity amongst others. The use of this mixed method study will be explored in detail in this section of the literature.

The VNOS-A was not seen to be appropriate to measure children's conceptions of NoS (Ayala-Villamil & García-Martínez, 2020). This might also be due to the nature of the questionnaire and the difficulty of understanding certain terminologies listed in the questionnaire. The VNOS form D includes questions such as 'What is Science?' and 'How is science different from other subjects studied at school?' The questions can be seen as being very straightforward and quite simplistic with regard to the nature of the language. However, only an individual view of science seems to be presented. Similar to other assessment tools, there is no presentation of the multiplicity of views which can co-exist within nature of science. The VNOS uses a coding rubric, labelling children's views as inadequate, adequate and informed against the aspects of science listed in tenets proposed by Lederman (1998). Akerson and Abd-El-Khalick (2005) has used the VNOS along with a coding rubric to analyse the students' understanding of certain aspects of NoS, such as the creative/imaginative aspect, the distinction between observation and inference and the tentativeness of science. The research questions were not distinct in the study, however the above aim was implied. Together with the VNOS this study also interviewed the eight child participants to contextualise students' questions with the above mentioned aspects of NoS. While there are concerns with the views of science amongst teachers and children, there are no suggestions for interventions for teachers. Moreover, studies within primary science education have mostly focused on evaluating students' and teachers' views of NoS and to a less extent to inform teaching (for example see Khisfe, 2008; Cofre et al., 2019; Akerson and Donnelly, 2010).

Scwartz and Lederman (2002) proposed a revised form of the VNOS titled VNOS-B, this revised questionnaire was used to assess secondary school teachers views on aspects of NoS outlined in the tenets of NoS proposed by Lederman (1998) himself. Several questions from form A were amended to provide a more coherent questionnaire with several questions put in context and the means to understand the relationship between tenets proposed by Lederman and were asked to justify the different key terms such as theory that were mentioned in the questionnaire. The VNOS-C was later published by Lederman (2002) as the most reformed questionnaire in that its content is able to generate a wider understanding of views within NoS. The VNOS-C was developed for use with children and older students in mind and

Several studies have used the VNOS-C proposed by Lederman et al. (2002) with teachers from both primary and secondary schools. Sen and Sari (2017) have used the VNOS along with teacher belief interviews (Luft & Roehrig, 2007) with thirty seven teachers to create teacher profiles based on discourse and the meanings communicated about the methodology of science, nature of scientific processes and the language of science. Lederman and Lederman (2004) have used the VNOS among primary school teachers to understand conceptions of NoS and scientific inquiry after carrying out lessons from the project ICAN.

Despite the several attempts to perfect the VNOS as a tool to measure children's NoS views, there are many drawbacks in relation to the lastest VNOS-D. These limitations pertain to: the content of the questions, the broadness of the questions, and the context of the questions (Ayala-Villamil & Garcia-Martinez, 2020).

With regard to the content knowledge of the questions, the questionnaire does not assess all the aspects of NoS (Ayala-Villamil & Garcia-Martinez, 2020), making the questionnaire limited to assessing only the empirical, tentative, inferential, creative and imaginative and the distinction between the observation and inferential aspects of nature of science (see Lederman & Abd-El-Khalick, 2002).

Furthermore, the questions are quite broad for young children to understand such as 'How certain are scientists about the way dinosaurs looked?' and 'If scientists all have the same facts about dinosaurs, why do you think they disagree about this?' (Lederman & Abd-El-Khalick, 2002). The examples used to question students are not directly related to children's experience with the world around them or the science content that they have learned at school, for example dinosaurs do not feature in the Maltese Curriculum (DfQE, 2022). The VNOS could have incorporated better scenarios for its questions which are more aligned with children's experience of science such as global warming or in relation to the topics that students study at school such as *forces* when assessing children's inferential andobservational standpoints of science. Other questions which are listed in the VNOS can also appear lacking relevancy due to their all-encompassing and unsuitable questions (Allchin, 2012).

The VNOS-D has some limitations with the universality of questions, especially in relation to the context of the questions. Some questions such as 'Do you think that scientists use their imaginations and creativity when they do their work?' have been placed without background and context and in a very formal structure. This makes it by far more difficult for children to answer such questions and expand on their answers. It has to be regarded that children's experience with science and their understanding of the world around them is quite limited to what they have been exposed to both at home and at school (Illeris, 2016; Obe, 2018). With this notion in mind it would be considered quite understandable that children understanding of the questions, as well as the format and structure that has been used in the VNOS does not quite relate to children's school science.

A more child friendly version could have also been utilised by incorporating visuals such as pictures, concept cartoons, diagrams, etc. so as to elicit more from the students and offer the possibility of an ongoing dialogue with children by understanding where their interests lie.

The VNOS is still a useful tool to measure teachers' and children's conceptions of NoS due to its ease of administration (Ayala-Villamil & Garcia-Martinez, 2020). More commonly, it is being used in interventional studies. For example, Valencia Narbona, Nunez Nieto & Cofre Mardones (2022), used VNOS to explore teachers' understanding of NoS before and after an intervention.

Brunner (2019) used VNOS to test the effectiveness of an interventional study on the explicit –reflective approach for teaching NoS. His interventional study was based on the reading of trade books with students. The trade books which had NoS aspects such as observation and other scientific methods in 'I Galileo', were provided to the participant teachers along with content boxes and NoS descriptions to aid the teacher in teaching NoS aspects. The VNOS was administered on teachers before and after the study to see whether teachers' use of explicit-reflective approach can inform their views of NoS. The study has shown that an explicit-reflective approach to teaching NoS can positively influence children's understanding of NoS. The results have been backed up by

Sutherland and Dennick (2002) used a mixed-method approach to study on what terms Western science is perceived differently than Aboriginal science. Thus, they administered a questionnaire based on a Likert scale to seventy- two grade seven student participants and conducted a semi-structured interview post the questionnaire to validate the answers given. The interviews with students were conducted with lots of scenarios for different points of discussion. Another study which used questionnaires with a twenty-four point Likert scale was conducted by Forawi and Abdallah (nd), who measured 307 primary school students fromthe UAE on the conceptions of NoS that students hold. They sought to identify if a relationshipexists between students' conceptions of science and their gender. The questions within the questionnaire were based on a Likert scale with illustrations of images. The use of faces to on the Likert scale were used to help with the understanding of the Likert scale. The questions included six folds of NoS across the NoS tenets proposed by Lederman (2013).

3.5. What do we know about children's understanding of Nature of Science?

A selection of empirical studies and review documents (Lederman, 2013; Akerson & Abd-El-Khalick, 2005; Soeharto et al., 2019; Akerson & Donnelly, 2010; Lederman et al., 2002; Khishfe, 2008; Cofre et al., 2019) have labelled children's and teachers' understandings of NoS as informed, naïve and transitional. These judgements on understanding have been based directly on the characteristics of NoS determined to be appropriate for science education such as Abd-El-Khalick's statements on NoS (1998) and Lederman's 'tenets of nature of science' (1998; 2002) (see criteria of the instruments described in the earlier section 3.4.). For example, Nehring (2020) described these views as being placed on a continuum with naïve and informed views at the end of each spectrum.

Chen et al. (2013) relied on statements taken from 'Nature Of Scientific Inquiry' (NOSI) which assigns informed, transitional and naïve views. Statements such as "there are many possible ways to solve a science problem" generated an informed view, whereas statements such as "there is only one method and one set of steps to do an experiment", were considered as being naïve views. In this sense, informed views are ones which conform to the standards or 'tenets' for nature of science in science education. While naïve views are ones which are considered to be 'misinformed' in that they do not match with the standards or 'tenets' of nature of science. There are several concerns with having this classification of views; firstly the dependence on predetermined statements suggest one definitive view of science which is problematic as it does not allow for a multiplicity of views (and thus, not reflective of the multiplicity of views presented in the philosophy of science). Secondly, the criteria for each judgement on each individual view suggest that alternative views of science cannot co-exist

(Shtulman & Valcarel, 2012). Thirdly, these evaluating statements (Shtulman & Valcarel, 2012) do not provide a clear focus in terms of what children and teachers actually know aboutthe nature of science, other than that their views do not match with what is taught (or the sort of view/s that are promoted) in school science.

Furthermore, the lack of understanding with regard to why children have such views of NoS calls for a more qualitative approach to the study of NoS. However, up till now qualitative studies have not yet identified what shared understanding children and teachers have about science, and whether there is a particular view of science which is projected by school children and teachers. Despite these attempts that have been made to measure the different views of NoS, many studies have opted for a quantitative measure such as questionnaires or a mixed method approach which is often in the form of a questionnaire followed up by interviews (Schwartz et al., 2002).

Quigley, Pongsanon and Akerson (2011) have used the VNOS-D before and after an interventional study to measure the extent of children's improvement in understanding NoS aspects based on the "tenets" of NoS. The VNOS-D was admistered as an interview due the reading and writing abilities of the young child participants. Alongside the VNOS-D, class discussions and journal writings were also used as part of a mixed-methods study to generate a more thorough understanding of the target aspects of NoS. The form is not a published version, however it has been used in other studies including in Akerson's (2014) study which explored third graders' conceptions of NoS pre and post a one year interventional study. The VNOS, was used as an instrument to track students' NoS ideas and how these ideas were challenged in discussions. As suggested by Quigley et al. (2011), the VNOS-D was a more appropriate tool than its previous versions to identify and understand primary school's views of NoS. However, despite its extensive use with primary school teachers, using the tool with younger students is quite limiting as the seven item questionnaire does not offer a wide understanding about NoS conceptualisations and as discussed in section 3.4. questionnaires require adaptation for use with children due to the content and context of the questions. These can have a big effect on the responses that children provide.

3.6. What do we know about teachers' understanding of Nature of Science?

> *Teachers' language, cookbook laboratory activities, textbooks that report the end products of science without addressing how the knowledge was developed, misuse of important words having special meaning in a science setting and traditional assessment strategies are just some of the ways students develop conceptions about the NOS. Ever present in science content and science teaching are implicit and explicit messages regarding the NOS. The issue is not whether science teachers will teach NOS, only what image will be conveyed to students*
>
> (Clough, 2006, p.2).

The pedagogy of science in schools is a great influence on students' conceptualisations, beliefs and attitudes towards science (Clough, 2006; Fauth et al., 2019). Teachers' understanding of science is mostly limited to their own experience of school science (Abell, 2013; Lederman, 2013; Obe, 2018), and a general public understanding of science. Knowledge about science is only one competence for teaching school science (Matthews, 2014). The importance of having a good understanding of the nature of science is often neglected (Lederman, 2013). This is problematic as teachers should have all three competencies for teaching science whichare; understanding of nature of science, good pedagogical content knowledge and scientific skills (Matthews, 2014; Van Driel, 2021). It is favourable to develop teachers' understanding of science and its nature due to its effects on the teaching of science in the classroom (Ozgelen, Yilmaz-Tuzun & Hanuscin, 2013).

To identify teachers' beliefs and their relationship to classroom practice, Brickhouse (1990) conducted a study with three science teachers of varying backgrounds to examine the relationships between teachers' scientific knowledge and the methodologies that they applied in the classroom. Brickhouse found that the teachers' views of NoS are expressed in their teaching approaches, their class room behaviour and their own views of science and scientists. Content knowledge is seen to be given great priority over science skills such as inquiry or learning on NoS in science classrooms (Abell, 2013; DeBoer, 2019).

On the other hand, Lederman (1999), recognises that teachers' perceptions of NoS, their own scientific experiences, and their views of science reflects in their teaching of science. Studies have shown that there is a link between teachers' teaching approaches and their teaching beliefs to their beliefs and conceptions of NoS (Buehl & Beck, 2015; Capps & Crawford, 2013; Karisan & Zeidler, 2017). Sen and Sari (2017), investigated the kind of beliefs that teachershad about science education, the perceptions of NoS that they hold and whether there is correlation between the two. Their investigation was conducted with thirty-seven teachers from secondary schools using both the VNOS and Teacher Belief Interviews developed by Luft& Roehrig, 2007) as tools for the investigation. The study found that teachers have generallya good understanding of the empirical, socio-cultural and creative aspects of NoS, however, they found definitions of certain NoS terms such as theories and laws to be challenging. A positive correlation was found between teachers' beliefs and their perceptions of NoS. Teachers with more reformed teaching beliefs such as teachers who belief in student-centred lessons and inquiry, showed a more appropriate understanding of NoS. The results confirm that teachers' understanding of science transmits into their teaching practice.

Piliouras et al. (2015) who conducted a case study consisting of two teaching sequences with eight primary school teachers report that teachers who ask appropriate questions during science, seek scientific discourse in class in the form of scientific arguments and offers possible alternative solutions are those teachers that promote appropriate 'tenets' of NoS such as that there are many different methods in science, and that science is not absolute. The teachers were made to document their lessons and reflect on the discourse of the lessonsprior to the second teaching phase. During the second teaching phase, the teachers were asked to document their lessons and report any differences. It became evident from the studythat in the first phase teachers used pre-established answers from textbooks which they haveused religiously during the lessons. Lessons were teacher-centred and focused on reading and writing rather than seeking critical thinking, problem-solving and inquiry-based skills. Reflection on the discourse analysis led teachers to be aware of how they communicate withchildren during science, noting that appropriate questions linked to higher order thinking skills were not being encouraged. The study has also led to teachers acknowledging what image of science is being presented to the students and what influences exist in terms of thepractices and meanings communicated in science. The study suggests that teachers' understanding of science is critical in identifying the sort of science being taught in schools and the images of science being presented in the classroom.

The teachers' conceptions of NoS can be influenced by a number of variables including teaching discipline, teaching experience, region, educational level and gender as outlined in the study by Karaman (2016). The 'Scientific Epistemological Views Questionnaire' developedby Liu and Tsai, have been used by Karaman (2016) to identify the demographic variables influencing conceptions of NoS amongst teachers. The study with 647 teachers showed that no significant effect was seen in terms of the gender and educational level of the participants however a significant effect was seen between the location of the participants and the teaching experience. The difference between science teachers and elementary teachers was significant, favouring science teachers, especially in four aspects including; social negotiation, tentativeness, creativity and theory-ladedness. However in the theory-ladedness, primary school teachers scored higher than physics teachers, showing that having a strong background in Science does not necessarily mean having a very good understanding of NoS. Moreover, the results show that there is quite a gap between secondary school science teacher' understanding of science, and primary school teachers' understanding of science.

Teaching is one of the major influences that come to play in relation to children's ideas, amongst other influences such as media, schooling and literature (Karisan & Zeidler, 2017). Interest in the influence of teaching and classroom practice on children's perception of science was seen by Hammerich and Blouch (1996), to explore the relationship between teachers' conceptions of NoS and their consequent conceptions of teaching science. The study was conducted with forty-seven participant teachers who were given an open-ended questionnaire, followed by an interview to elicit the sort of views that teachers have both in relation to science education and to science as a discipline. Results indicate that teachers built their conceptions of science based on their own past experience of school science and their engagement with science resources (including textbooks), and less with their involvement with the scientific practice. It was also reported that teachers acknowledged the subjectivity of science and have described science as a process of discovery; i.e. that science is a process of both creating and justifying new knowledge. The results show the importance that teachers reflect on their understanding of science to identify the sort of science they are promoting in their classroom and how this affects their classroom practice.

In the secondary school context Mellado (1997) similarily acknowledged classroom practice as being directly/ indirectly related to teachers' views of NoS. A questionnaire was administered to four student secondary teachers in the study to assess views related to a number of issues, especially in relation to the participants' conceptions of the nature of science and how these relate to classroom practice. In addition to the questionnaires, Mellado also used follow-up semi-structured interviews as well as classroom observations for the participants to justify their responses and to support their views. He found that teachers' did not have an adequate understanding of NoS, however there was no significant relationship between their own conceptions of NoS and their classroom practice as none asserted their own ideas in science lessons. From the study it was found that the teacher with the most positivist view of science had the most constructivist approach in the classroom. This, shows that teachers' views of science do not necessarily inform and transcend to their classroom practice and teaching approaches. However, it should be acknowledged that teaching practice and education has changed since the 1990s as the study by Piliouras et al. (2015) confirms. Piliouras et al. (2015) who studied eight primary school teachers looked at a). the image of science presented by teachers b). what influences practice and direction of science during lessons c). the meanings communicated regarding the methodology of science d). the meanings communicated regarding the nature of scientific processes and e). the meanings communicated about the nature of language in general and the language of science in particular. Two teaching phases were conducted and assessed in relation to the research questions and VNOS was conducted to the participating teachers. The results show that teachers who ask appropriate questions (i.e. those who seek for arguments and ask for alternative solutions and promote scientific inquiry) have shown to have appropriate tenets of NoS as they have scored higher against the VNOS, whereas teachers who scored lower in the VNOS were teachers who demanded pre-established answers from science textbooks and whose lessons were more teacher-centred and content focused. These teachers' answers to the statements listed on the VNOS did not match and thus their views were labelled as being 'misinformed'. These results support the idea that the type of understanding of nature of science that teachers have influences their teaching practice when it comes to school science.

Similar results were shown by Rahayu & Widodo (2019) who used quantitative survey with a twenty-eight point Likert scale to measure primary schools teachers' views of Nos (both pre-service teachers and certified teachers) against aspects of NoS such as (tentativeness, creativity in Science, social and cultural embeddedness. etc). The level of responses were categorised according to the different levels of understanding as established by Lederman (1999), such as naïve, transitional and informed views of NoS (refer to table 3.6.). The study found that albeit the study showing a good general understanding of Science, certified teachers had a better understanding of science than pre-service teachers. This could indicate that experience is a determining factor in good understanding of Science, regardless of teaching training. Rahayu and Widodo's study confirms, Ecevit, Yalaki and Kingir (2018)'s study with sixty-five student teachers in their third year of study. The semi-structured interviews based on the VNOS and observations during the interventions confirms that teachers views of science do not match the statements of VNOS deemed appropriate for science education, for example many did not regard science as being tentative or subjective. Ecevit et al.'s study also suggests that teachers' views of science progressed as a result of the interventions.

Naive	• Consistent with a positivist view of science • Empiricist • Science is seen as unsystematic (science follows a random procedure) • For example; participants understanding that science is a trial and error process is considered a naïve view of science.
Transitional	• Participants' views are not naïve but still not informed. For example; participants may consider that scientists observe and it is theory-driven, however, they may not consider that scientists have assumptions that guide their practice has coined this stage as partially-informed
Informed	• Consistent with a relativist view of science • Science is seen as systematic (science is guided by theory and hypotheses) • Constructivist view of science • For example; participants recognise that science is guided by ideas (hypotheses) and that science is not just any random work or procedure (Lederman et al. 2014)

Table 3.6. Naïve, transitional and informed views of NoS (Abd-El-Khalick, 2012; Lederman et al., 2014).

As can be seen from the table above, teachers' results within this section of the literature review indicate that teachers' seem to hold views of nature of science quite different to what it seen as appropriate in terms of school science. It is noted throughout the literature review that by standards of science education, teachers' views should conform to a relativist and constructivist view of science. However, the results from this review suggest a traditional "naïve" or "transitional" view that is built on the idea that science is unsystematic. The organisation of teachers' ideas and their understanding of the nature of science is yet to be defined.

3.7. Summary

Taken together, the studies within this literature review suggest that both teachers' and children's views of nature of science do not conform to the pre-established characteristics of science set for school science.

Furthermore, in the literature, children's voices tend not to be heard. While there is a range of literature addressing what children and teachers know about science, little is known about how children and teachers make sense of the nature of science; how they view science, what they believe, and how they arrive to such ideas about the nature of science. The review indicates that there is a gap in research in providing a collective understanding of science which enables children and teachers to share 'common sense' knowledge about the nature of science.

Chapter 4

Social Representations Framework

The literature review in chapter 3 pertaining to children's and teachers' ideas about nature of science, establish the need to have a collective understanding of children's and teachers' hidden assumptions about nature of science. This chapter will address a). how social representations are created from dialogue, b). the meaning of a social representation, c). the theory and method(s) of social representations, d). the aims of social representations to understand socially constructed ideas, beliefs and assumptions , and e). how social representations have been used in previous studies. This chapter will conclude by justifying social representations as a framework for this study.

4.1. What are social representations?

Social representations are the dynamics that connect common sense knowledge (lay-people's knowledge) and the expert and professional opinion (de Rosa, 2013, 2019; Sammut et al., 2015). Individuals are continuously shaping their assumptions about a concept or phenomena (such as science), based on their thoughts and interactions with others (Wagner, 2020). These assumptions become 'common knowledge' about science and are shared by members of the same social group (Sammut et al., 2015).

The term 'social representations' embodies a multitude of concepts. First introduced by Moscovici, social representation is defined as:

> A system(s) of values, ideas and practices with a twofold function first to establish an order which will enable individuals to orient themselves in their material and social worlds and to master it; and secondly, to enable communication to take place among members of a community by providing them with a code for social exchange and a

code for naming and classifying unambiguously the various aspects of their worlds and their individual and group history.

(Moscovici, 1973 p. xiii)

Hoijer (2011) defines social representations as "common ways of conceiving, thinking about and evaluating social reality" (p. 4). More recent studies that have used social representations as a framework adds that, "social representations are concerned with how people make sense of unfamiliar information" (Smith and Joffe, 2013, p.17).

Created as a result of how social groups understand the world, social representations were defined by Sammut and Haworth (2014) as

A way in which participants engage in. Social representations are sustained by a thinking society, a society in which it draws on its collective experience of the nature of science (p. 11).

A social representation can be in the form of a visual that acts as a shared code. This will ultimately enable participants to communicate collectively on the given code/visual. Thus, a social representation allows different interpretations through collective communication. The term 'collective' is used here to mean 'with others'.

According to Moscovici (1976), and Lahlou and Abric (2011), a social representation is dual in nature; it refers to both the process of arriving to a social representation, as well as the content of the representation itself. The process of the representation considers the psychological operations of the group. It involves the recognition and exploration of the object (in this case science) amongst the group. The process of the representation is entirely based on the group members experience with the object (science) and their sense-making. On the other hand, the content is the product which emerges from the process (sense-making). It is the presentation of the object (science) into what is familiar to the group. This can be in familiar dialogue or images which represent science (Moscovici, 1989).

4.2. Why are social representations useful?

The act of representation is in itself a social process by which social groups draw on an existing shared code of knowledge (Flick, 2017). As a framework social representations seeks to elicit and examine the network of ideas, beliefs and values by understanding the wealth of perspectives placed in a social context (Flick, 2017; Sammut and Haworth, 2014). The reinforcement of social representations is fostered by the interaction of the social environment (Crisp and Turner, 2010) including schools, teaching approaches, learning behaviours, teaching practices and attitudes.

The propositions are based on the assumption that learner knowledge is built from their own experience. During the process of learning, they form mental representations, which are shaped by their social and biological experiences, as well as their dispositions. The process of learning requires an active mental process which integrates the learners' vision and his understanding of his surroundings in a conflict between the learner's thoughts and what he finds and understands through his conceptions. A learner's mental model must be rebuilt when new information is introduced to the pre-existing representation (Giordan, 2000).

In 'common sense, science and social representations', Farr (1993), argues that social representations show how common sense thinking about unfamiliar information develops. Social representations is one approach for revealing the often unspoken assumptions that children and teachers have about NoS. It is useful to identify what children and teachers assume science to be, and what they think (philosophically) about NoS. This is because social representations can give valuable contributions to school science. It can help policy makers and educators understand what children know about science and the way it works to enable curriculums, teaching pedagogies and educational resources that align and build on children's social representations of science. Acknowledging the shared ideas that children and teachers have about NoS would help in implementing learning activities that target and challenge children's ideas and views of NoS.

4.3. The use of social representations to understand teachers and children's understanding of the nature of science

The kind of science that children are familiar with is greatly varied from the kind of science that other social groups are familiar with, such as practitioners' views of science, or scientists' views of science due to the difference between public science, real science and science education (Takach & Yacoubian, 2020). Children's experience of science is often limited to school science (Van Griethuijsen et al., 2015). School science is laden with content knowledge that children have to learn as part of their formal education (National Curriculum Framework, 2011; Abell, Appleton & Hanuscin, 2013). Children might see science differently to scientists, philosophers of science and teachers. Having children and teachers social representations of science can provide us with a school-based social representation of science.

With social representations as a framework for this study, it will take as its starting point the shared understanding of science and nature of science of older primary school children, communicating their shared ideas and values to encapsulate a common understanding that represents their social group (Foster, 2003b).

Children's social representations of science have not yet been investigated. It has been discussed that the use of social representations can extend to justify what should be taught, how and why it should be taught such as in the case of science education (Dunlop, Atkinson, Mckeown & Turkenburg-van Diepen, 2021).

The use of this framework to elicit children's views can create a sense of identity which therefore creates a common code for children's ideas and beliefs (Howarth, 2002). Focus groups to understand the children's views can become a way of collectively understanding and interacting with knowledge based on somewhat shared experiences. How children see science is dependent on the values, beliefs and ideas that they attribute to science, thus their constructions of science is heavily dependent on their conceptions of science (Lo Monaco, Piermatteo, Rateau & Tavani, 2016).

The use of social representation theory as a framework for this study can help identify present social representations of science and in turn, of nature of science but also to understand the processes and influences that are leading children to hold on to these social representations.

What children think about science or what the public thinks about science might be researched in a traditional framework which has been previously employed by various scholars in the field of NoS such as using the VNOS or attitudinal surveys such as the TOSRA. However, drawing inspiration from Moscovici (1961), a social representation approach will be considered to enable the construction of lay explanations for understanding NoS by offering children and teachers' voice, as well as a suitable instrument to articulate their own ideas of science.

The term 'science' is a familiar term that children and teachers at school use to refer to the school subject, or what they read about in the media (Obe, 2018). Cobern and Loving (2001) argue on the many definitions of science and suggest a distinction between science as a school subject and real life science. The difference between the nature of the science done at school and the nature of real life science, can be influential on children and teachers' understanding of NoS. All individuals have a certain image of what science actually is and how it operates based on their integration with science as students/teachers, as well as the participation in socio-scientific issues. It is thus appropriate for this study to first look into teachers' and children's ideas about science by prompting children to initiate dialogue about NoS through picture question cards.

Nature of science is often taught implicitly at school (Lederman & Lederman, 2014)- partly due to an emphasis on examined content (Abell, Appleton & Hanuscin, 2013). This suggests that children and teachers might benefit from explicit discussions on nature of science; what science is, what scientists do, how we justify the science learned at school and how we differentiate science from other disciplines.

Due to the way science is presented at school, and the way it is taught, children are familiar with the products of science, i.e. scientific knowledge and scientific applied knowledge (Lederman, 2013). On the other hand, the aims and processes of science are rarely given the spotlight in science education (Erduran & Dagher, 2014; DqFE, 2022; Mostafa, Echazarra & Guillou, 2018). Children's images of science corresponds greatly to their collective conceptions of NoS, which will allow them to discuss in great depth their outlooks on NoS through stimulating questions sustained through dialogue.

The common sense view of science explored from children's dialogue in the study will help articulate what sort of ideas and students hold about science which can ultimately influence policy makers, teachers and academics to respond to these views and knowledge(s) of science by designing effective material and approaches that can build or challenge these social representations (Martikainen & Hakokongas, 2022) . It would be appropriate to use this study as a foundation to understand what children already know (i.e. what sort of knowledge that they have about science) and understand how these can influence learning.

Social representations are both the result but also the process of social integration and construction (Wagner & Hayes, 2017). This means that social representations constitute both the individuals' ideas in the social context they were developed, as well as the integration of these ideas into a 'shared' discussion. As a product of social reality, social representations are often changing, re-interpreted and re-evaluated depending on context and time (Farr, 1993; Flick, 1994). The relevance for Moscovici's (1973) theory of anchoring and objectification in this study lie in how participants will construct their current knowledge about science; the anchoring process, and with the help of the process of meaning making familiarise themselves with what is still unfamiliar. This is then known as the objectification process of social representations. The act of shared knowledge and with the use of visuals will help children get talking about its relation to the science that they are familiar with, and thus will be able to draw up their shared ideas about science.

The process of developing social representations is reliant on what Moscovici (1988) has termed as the process of anchoring and objectification. This process is built around making sense of strange and abstract concepts into more concrete and familiar ones by transferring what is in the mind to something physical in the physical world. Therefore it is reliant on different interpretations which come together through dialogue. As a cognitive process of meaning making, objectification and anchoring helps categorise the deep 'hidden' assumptions that one has about nature of science by objectifying their beliefs about NoS into discourse (concrete), sustained by visualisations (cards) and dialogue (focus groups/interviews) on the subject.

Anchoring is a process which turns something unfamiliar into something known. Talk is one way in which individuals are able to structure their thought and share their understanding with their group members (Hoijer, 2011). Talk helps establish an order which enables members of the group to be acquainted with their views of science, and enable communication about science by providing a code for knowledge exchange. Social anchoring is important because it structures the understanding of the whole group. Participants collectively elaborate on the social object (which in this case is science) and interpreting it in their own familiar terms through dialogue. The process of anchoring is a joint effort in which participants reflect on what has been discussed and present their feedback, building on each other's thoughts and cognitions. The use of visuals will open children to discussion about science drawn from their associations. The process of anchoring is reliant on the processing of information and the interpretation of new information to build and frame one's own perceptions and knowledge (Sammut & Haworth, 2014).

Objectification is then the presentation of social thinking. This is where the anomalies are anchored into context to ground unfamiliar concepts into something which participants can discuss and associate with. Social representations characterise the individuals' cognitions and connect these cognitions into a network of ideas (Sammut & Haworth, 2014).

4.4. What are the appropriate methods for studying social representations?

Social representations has been used as a framework in several studies to help understand different concepts relevant to social systems (Howarth, 2006; Purkhardt, 2015) such as studies in identity and disability (Devenney, 2005; Harma et al., 2013; Rizzo et al., 2021; Richa et al., 2022) and climate change (Hoijer, 2010; Moscardo, 2012; Flores, 2018). Social representations has been used in many studies in the domain of public understanding (Horote & Hernandez, 2020; Smith& Joffe, 2013; Uzelgun & Castro, 2015) and has been used quite recently to understand the public opinion on the Covid-19 pandemic (Ittefaq, Albwao, Baines, Balmas, Kambah & Figueroa, 2022; Wassler & Talarico, 2021).

Few studies have dealt with social representations in educational contexts, or with science related to social representations. For this reason, most of the studies I will review within the educational context are taken from disability studies such as (Devenney, 2004) and from subjects taught in schools such as social representations on maths assessments (Martinez-Sierra et al. 2016; Martinez-Sierra & Miranda-Tirado, 2015; Lopez-Lopez et al., 2022).

Studies such as Moscardo (2012) addressed societal issues such as climate change and used social representations as a framework to understand the public's understanding and associations to this persisting issue in society. Social representations were understood to provide a window into how people from different cultures (U.K. and U.S.A.) articulate their own knowledge, beliefs and ideas about climate change into familiar discourse.

Understanding people's construct and the way they represent social phenomena as a group is critical for understanding deeper connections between their associations of the object or phenomenon under scrutiny. Devennay (2005) for example, sheds more lot on the importance of associations in the public's social representations on disability.

A study by Farr explored and critiqued death and traditional models of grief using the social representations framework to draw upon and illuminate the different perspectives and expressions that make the concept of death familiar through Moscovici's process of anchoring and objectification through symbolic interpretivism. This was done through the use of images that relate to death such as the symbol of the cross and the coffin to anchor the participants to explore their own understanding of death. The objectification process was the part in which the participants made sense of the symbols of death to build and share ideas on what it means for them, such as exploring the relationship between religion and death.

Other studies have tackled societal issues through social representations such as Health (Flick, 2000), Tourism (Moscardo, 2010), human rights (Doise, Spini & Clemence, 1999) and world history (Liu et al., 2015). Social representations have been used to discover how different members of society understand the topic of interest and how they shape their ideas about it. Commonly, these studies have used focus groups and interviews to explore social representations through a common code for communication. One consistent method explored in all studies is the need for social representations to be grounded in communication (Martikainen & Hakokongas, 2022; Kitzinger, Markova & Kalampalikis, 2004).

In education, causes of bullying has been defined and elaborated on through social representations by Thornberg (2010) whose use of social representations as a framework for the study helped identify several forms of bullying built on children's ideas and a deep elaboration of these forms based on children's discourse in the qualitative interviews conducted with the fifty-six student participants involved. Thornberg's study (2010) used grounded theory approach, together with theoretical sampling to analyse the interviews conducted with children. In the analysis, social representations was used as an instrument by which concepts taken from the data, were framed.

Thornberg's study utilised a different method to the one used by Miguel et al. (2010) to explore the social representations of the concept of intelligence amongst parents and children. In this study, unlike the majority of other studies, the researchers used quantitative methods to identify a relationship between attitudes and behaviour. Such an approach has helped the researcher to tackle the different forms of child intelligence based on the different representations provided by the different social groups involved including the difference between parents' representations or in other words their conceptions of intelligence/ giftedness and teachers' own conceptions of intelligence/ giftedness. Furthermore, the social representations framework enabled the researchers to examine how the system of values, ideas, beliefs and attitudes (the social representations) translated to the way children act towards their parents' understanding of intelligence and whether their attitudes had an impact on behaviour.

The understanding of mathematics amongst students has also been explored by Martinez Sierra, Valle-Zequeida, Miranda-Tirado and Dolores-Flores (2016) who used social representations to understand how mathematics assessment is articulated by high school students. They defined social representations as "representations of reality, constructed and communicated among different social groups" (p. 249). The study identified what advances are required to improve students' assessment for more positive outlooks when it comes to the teaching and learning of mathematics by looking at 'common sense' knowledge' collectively voiced and developed by the students themselves. In their data analysis, they have utilised a thematic analysis approach to identify how maths assessments are 'talked' and made sense through the eyes of the students by allowing for the exploration of patterns within the data set. The results obtained identified the main idea/theme within the social representations, however, the characteristics by which the main idea/theme is maintained or developed remain absent within the study.

Martinez-Sierra and Miranda-Tirado (2015) have also investigated students' and teachers' social representations of teaching and learning in mathematics by using a phenomenographic approach to give voice to the participants and to give importance to the social experiences of students' and teachers' relationship with mathematics, acquiring a narrative approach to the sort of images and conceptions that these participants have about mathematics. Focus groups were used as a means to generate verbal narratives in relation to social representations. A comparative analysis was used to compare the teachers' and students' ideas about mathematics by categorising the participants' responses and thus finding similarities and differences in students' and teachers' social representations of mathematics. This research has been restricted to finding similarities and differences between teachers' and children's social experiences of mathematics, however, the study has managed to capture and in-depth understanding of students' and teachers' views on the teaching and learning of maths; showing how mathematics serves different social purposes between the two social groups. Nonetheless, the social representations explored in the study give an idea of what is conventional or not conventional in terms of the teaching and learning of mathematics.

The social representations framework has previously been used for a doctoral dissertation to understand the social representations of disability (Devenney, 2005). The study used a set of photographs of different people some with a physical disability, others with a hidden disability and the rest with no disability. The participants created a set of stories to represent each of the photographs. The storyboard technique was used with two hundred and eleven participants in focus groups sessions to analyse the type of fears, myths and beliefs that both participants with disabilities have about disability as well as what people with no disability think of people with a disability. The focus groups sessions was also followed by analysing print media articles that have disability as the central focus. The social representations framework helped identify a set of typologies that represent disability in this modern age. Thus, a typology of the social representations of disability was conducted. Social representations was a useful way to understands different views of disability and how people think of and understand the concept.

In summary, it has been shown within this review section that social representations have been identified using a variety of methodologies, both qualitative, quantitative or mixed methods and with a variety of methods which range from interviews and focus groups to questionnaires. While there is no limit as to how social representations can be explored, there are some considerations depending of the needs of the study. However, one aspect of social representations that remain constant is the need for communication. Other factors also include; similarities and differences between participants' ideas, the associations between participants' talk, and thirdly how the social representation is shaped by the group members.

In social representations qualitative studies are apt at encouraging participants to discuss the topic in more-depth, giving insight and bringing their own experiences of the topic/phenomenon. Several theoretical approaches and data analysis such as thematic analysis, grounded theory, central core theory and discourse analysis have been used to explore social representations qualitatively. One challenge faced by qualitative studies is a small sample. As Lo Monaco et al. (2016) suggests, social representations are made up of a common vision and an identity function. The identity function is questioned due to the small sample. It is seen as a challenge to identify the boundaries by which a social representation is developed. For this reason, Lo Monaco et al. (2016) suggests that a social representation is divided into two components; the main 'core' idea expressed in discussions and the criteria that has developed the main idea. The organisation is based on the criteria within a priority order. Lo Monaco et al. (2016) suggests that this organisation of social representations stays sensitive to variations in terms of sample size.

4.5. How social representations differ from the views of NoS

Social representations of science and views of NoS address different aspects of how science is perceived and understood. However, both social representations and views of NoS have important roles in shaping the public understanding of science within society. The table below outlines the similarities and differences between views of NoS and social representations of NoS.

	Social representations	Views of NoS
How they are formed	A social representation consists of more than one view. Each social representation consists of beliefs, practices, values and culture that serve to establish the way one behaves, thinks and acts towards the subject.	Views of NoS consist of opinions or knowledge. They inform people's perceptions about the subject which essentially relates more to knowledge and attitudes.

How it should be researched	Social representations delve into the culture and assumptions of a group within society. For this reason, a philosophical or psychological understanding will be required to explore more depth. To identify and explore social representations a stimulus can be used to engage participants in discussion. Participants bring their own contexts and examples to the discussions about the subject.	The knowledge or attitudes about NoS can be accessed through individual tests, as well as questionnaires and interviews.
How it helps with NoS education	It gives an idea of participants' experiences when it comes to NoS. Participants bring their own contexts which they develop through the course of discussions about the subject.	Prestated ideas which are meant to assess understanding. It explores the respondents' statements in different aspects of knowledge and attitudes.

Table 4.5. How social representations of NoS differ from views of NoS

Social representations of NoS and views of NoS each address different aspects both in terms of their research and their purpose for science education. Social representations deal with societal and cultural perceptions of NoS, whereas NoS views concentrate on the knowledge and underlying principles of scientific inquiry. Furthermore, social representations are formed through social interactions, media and cultural influences, public discourse and educational experiences, and thus not necessarily what is learned at school. Being context dependent, social representations are therefore dynamic and change over time. While, social representations reflects the stereotypes, assumptions and societal expectations of NoS, views of NoS enable individuals to make informed decisions when it comes to science.

4.6. Why social representations is an appropriate framework for this study

Individuals of all ages are actively thinking and making sense of what is contemporary in society, and its culture (Martikainen & Hakokongas, 2022). Sense-making is consolidated through the depiction of everyday life and its consequences, primarily making meaning withinone's own culture (Van Dijk, 2014). Beliefs are shaped by our own culture, as do experiences,insights and interpretations. Groups of people who share a particular culture (such as schoolculture), also share a common worldview filled with common ideas and beliefs (Martikainen & Hakokongas, 2022). Social representations (the system of shared beliefs, ideas and values)is thus developed, established or recreated by the group. Social representations serve distinct social purposes for those who share them, showing bothwhat's normal and conventional, as well as what's not. Social representations can provide uswith accounts of the nature of science which are collective to children's shared system of ideas, norms and beliefs about the nature of science, as well as that of teachers. A social representations framework is beneficial in that it shows how science in the existing Maltese school culture is realised and ascribed meaning to (by both groups of children and teachers).In doing so, children's and teachers' everyday common knowledge is acknowledged in the characterisation of nature of science in schools.

In conclusion, this chapter provided a discussion about what social representations are, how they can be identified in dialogue and how social representations were used in previous studies. Furthermore, social representations framework was addressed in relation to its use as one approach to studying children's and teachers' understanding of science in a collectiveway. The next chapter will be concerned with the methodology used to explore social representations within this study.

Chapter 5

Methodology

5.1 Overview

This chapter proposes a new methodology which aims to explore the ways in which the nature of science is socially represented amongst children and teachers. The purpose is to describe and justify the data collection methods, outline the procedures used to collect and analyse data and discuss the limitations of the study. This chapter shall answer the following questions:

1. What are children's social representations of science?
2. What sort of social representations of science do teachers have?
3. Are there any similarities and differences between children's and teachers' social representations of science?

5.2. Methodological underpinnings of the study

The underlying philosophical assumptions of this study are within an interpretivist paradigm (Cohen et al., 2009). In Thanh and Thanh's words (2015), "Interpretivism allows researchers to view the world through the perceptions and experiences of the participants…the investigator who follows an interpretive paradigm uses these experiences to construct and interpret his understanding from the gathered data" (p.24). The interpretive methods that will be utilised within the study all relate to understanding the shared meanings that children and teachers have about science mainly in relation to what science is and how it works.

The ontological stance of this paradigm is built on different worldviews constantly being negotiated in a social context (Klakegg, 2016). The ontology shapes the epistemological stance of this study and is built on understanding how these worldviews are constructed. An interpretivist approach offers the capacity for different understanding of how knowledge is constructed by children and their teachers, thus it considers the lived experiences and the ideas and views of the participants as constructs of realities (Mack, 2010). This study is in itself built around the idea that knowledge is socially constructed, with different interpretations and multiple meanings surrounding nature of science. It has been stated (Chalmers, 2013) that there is no single way of doing or viewing science, and as a result perceptions of science may or may not reflect empirical reality. Multiple representations can exist which are likely to influence how people speak and act in the world. True to the social representations framework, the aim of my study is to gain insight into how children and teachers represent the system of common knowledge about nature of science and how they see this as justifying certain elements and practices in society, science education, and the way society views science. Typically NoS is treated as a measurable construct for which individuals are assessed on their skills and knowledge about NoS. While there are better reasoned answers when it comes to understanding what science is and how it operates, this study will not focus on a singular but a phletora of viewpoints for which participants can reflect on and discuss with other participants.

The subjectivity that ties with interpretivism is appropriate in this study, not only due to the different interpretations of science seen throughout the history of science, and even today, but also due to the different everyday understandings and interpretations of science held by children and teachers (Cofre et al., 2019). In practice, the importance of sharing with children these scientific ideas and interpretations is to expose children to different ideas in relation to 'how science works' and to encourage children to think and talk about science. More so, the philosophical underpinning ideas about science, as well the philosophical methods used in this study will help children and teachers alike to understand different perspectives on what science is, and encourages reflection on these perspectives.

In contrast to existing studies on children's views about nature of science, the study does not aim to 'assess' children's views of nature of science, but to get them to make sense of their ideas when they engage in philosophical dialogue within the group. This engages children in thought about science as a social object which is more in-line with a social representation approach in studying children's and teachers' opinions and ideas about science (Cofre et al., 2019). Social representations are present in everyday life in opinions, attitudes and common-sense knowledge (Lefevre & Lefevre, 2014), and by studying representations in open discussion, rather than in relation to specific scientific contexts (e.g. palaeontology, …) allows us to better understand often-hidden ideas about science that children and teachers take for granted, but which might be important in shaping responses to science and scientific knowledge in the longer run, and beyond school. This is different from previous studies which have used pre-conceived statements about science to assess children's views of NoS (refer to literature review for detailed accounts of previous and current studies on NoS). In the following section, I will introduce the study design by discussing the approach used for the study and the methods utilised to gain access into teachers' and children's social representations.

5.3. Study Design

A qualitative approach was adopted to allow a deeper insight into children's and teachers' understanding of the nature of science. The study, which took place in Malta, involved focus groups with year 5 children (9–10-year-olds) and separate interviews with their class teachers. Seven teachers from different year groups were then recruited through acquaintance to the researcher. The seven participating teachers (from different year groups) were divided into two focus groups of three and four, respectively. Each focus group and teacher interview took the structure of a philosophical dialogue. As will be explained further in the next sections, philosophical dialogue is an inquiry-based group discussion. For a philosophical dialogue to take place a stimulus is required. Drawing from the philosophy of science a set of eight cards were created 'Wonder Wild' that challenge children as well as teachers to think about big questions in science and reflect about their own assumptions and how they fit in with the philosophers questions. Because there is not just one correct answer, children and teachers can evaluate different perspectives and reflect on their own response to them. With their response to the cards, participants reveal how they understand science, providing a good idea about what sort of learning needs should be prioritised to gain better public understanding of science. An evaluation of 'Wonder Wild' as a philosophical research tool will be discussed further under the section: Procedure.

5.1. How social representations will be used in this study

This study adopts a social representations approach to explore how children and teachers understand the nature of science. As defined in chapter four pertaining to social representations (see section 4.1.), social representations refer to a system of ideas, beliefs and values that enable groups within society to communicate about a social phenomenon (Moscovici, 1963). Social representations are both the result but also the process of social integration and construction (Breakwell, 1993; Wagner & Hayes, 2017). This means that social representations refer both to a process of constructing knowledge through meaning-making and dialogue, as well as the product of said thinking and dialogue.

As a framework for this study, social representations are seen as being socially constructed. This means that as an approach, it pays particular attention to the way participants ascribe meaning to nature of science by a process which Moscovici (1963; 1984; 2000) referred to as 'anchoring and objectification'. Anchoring and objectification make what is unfamiliar into familiar knowledge. For this reason, Hoijer (2011) suggested that members of a social group (such as children and teachers) ascribe meaning through their own experiences, relationships, beliefs and knowledge to something which is still unfamiliar, making it familiar. Through this process, their worldview (their prior knowledge) is associated to new knowledge through communication.

To encompass the duality of social representations as both a process and product of meaning-making, the structural framework proposed by Abric (1994, 2001) was used as a means to identify and characterise social representations from teachers' and children's dialogue within this study. The structural approach refers to the theoretical construction of a social representation which is aimed at organising the social representation. The organisation refers to the construction of ideas, developed through talk that form the social representation. This means that the structured approach takes into consideration how knowledge is co-constructed amongst group members (from an individual to a socially represented object).

On a clearer identification of the organisation behind the structure of a social representation, Moscovici (1996) studied the relationship that Catholics and Communists have with psychoanalysis. While both groups rejected psychoanalysis, the groups' reasons for the rejection were quite distinct. Moscovici thus argued that while both groups rejected psychoanalysis, their social representations were different. This study has encouraged Abric (1996) to tackle a new way of analysing and understanding social representations, one which takes into consideration the characteristics (the reasons) that make up the group's thinking and how these relate to form a social representation for that particular group.

The structure of a social representation is one which is made up of the elements of thought expressed by the group (also known as cognemes), and how these cognemes than relate to one another (analysis of the relationship between these cognemes). The structure represents the whole organisation of the representation- how the social representation came into being. Thus, the structure of a social representation is made up of characteristics which define and establish the social representation.

The study conducted by Aim, Decarsin, Bovina and Dany (2018) on health, provides a good example of a structured approach to social representations. From their study with one hundred and twenty adult participants, they identified two central cores making up the social representation of health; illness and well-being. Aim et al. discuss how the central core elements were developed from associations of participants in relation to health. Each cogneme (expression of thought) centred around either illness and well-being when participants discussed 'health'. Furthermore, the central core elements were interpreted in relation to other terms, also known as 'neighbouring clusters' or 'thematic clusters'. These clusters make up the peripheral elements of a social representation in that they add characteristics to the core elements. For example; Aim et al. report that several characteristics are attached to the core elements. Happiness and balance are two peripheral elements which are linked to well-being. Other peripheral elements associated with health include longevity which is related to lack of illness- a central element and prevention.

A structured approach to social representations exists in three main processes; a process of elaboration, a functioning process and the process of the notion that Social representations can be conveyed both at an individual and social level. Elaboration is a process in which thought is created and expressed- transferring what is in the mind to language familiar with others in the group. Therefore it is reliant on different interpretations which come together through dialogue. Elaboration is heavily reliant on another step which Moscovici (1988) has termed as the process of anchoring and objectification. This process is built around making sense of strange and abstract concepts into more concrete and familiar ones by transferring what is in the mind to something physical in the physical world. As a cognitive process of meaning making, objectification and anchoring helps categorise the deep 'hidden' assumptions that one has about nature of science by objectifying their beliefs about NoS into discourse (concrete), sustained by visualisations (cards) and dialogue (focus groups/interviews) on the subject.

In everyday language, Moscovici's process of anchoring refers to understanding social objects through cultural traditions appropriate to the group. Through anchoring, the group finds a common identification about the phenomena, which is developed through shared experiences and built through talk (Farr, 1993; Flick, 1994). Talk helps establish an order which enables members of the group to be acquainted with their own views of science and find commonality amongst other members of the group. Group members elaborate on the social object (which in this case is science) and interpret it in their own familiar terms through dialogue. The process of anchoring is followed by another process; objectification. Objectification refers to the reproduction of concepts in terms and symbols which are familiar to the group. This means that objectification renders the social representation as concrete in that it is not just made up of ideas or concepts within the mind of the individual, but becomes a new tangible idea or concept which carries meaning to the group (Smith & Joffe, 2013).

The process of anchoring and objectification in this study is accounted for in the way children and teachers construct their current knowledge about science (anchoring) with ideas about nature of science identified and established (objectification) as a result of interaction within the group (Farr, 1993; Flick, 1994; Wagner & Hayes, 2017).

Elaboration about science as a social object is reliant on the processing of information and the interpretation of new information that helps the groups build and frame their perceptions and knowledge (Smith & Joffe, 2013).This is where anomalies (about NoS) are anchored into context to ground and make the unfamiliar, familiar (Moscovici, 1961). The process of communication helps in developing each other's thoughts and elaborating on thatof others.

Social representations characterise the individuals' cognitions and connect these cognitions into a network of ideas (Wagner & Hayes, 2017). As a theory, social representations put forth how such conceptions of nature of science are exhibited and developed through language (Hall, 2020). The theory takes communication as the central dimension to explicate the shared representations that children have about science, a wealth of perspectives and ideas are encouraged and fostered through interaction with others within the same social group to explore how ideas about nature of science develops (Hoijer, 2011).

5.4. Procedure

To explore the social representations of NoS amongst teachers and children, a qualitative approach was adopted for this study. Interviews and focus groups with teachers and children were conducted; two individual semi-structured interviews and three online focus groups with primary school teachers, and six online focus groups with year 5 primary school children. Grounded in philosophy in both theory and methods, philosophical dialogue was used as method by which focus groups and interviews were conducted. A set of cards compiled with philosophy of science statements and questions were used to initiate and sustain philosophical dialogue in both focus groups and interviews. Participants' philosophical dialogues were then analysed using a structured approach to social representations.

5.4.1. Pilot Study

A pilot study was carried out with students undertaking the postgraduate certificate in education (PGCE), in-service and pre-service teachers and children to ensure that the methodological approach is sound and that the research instrument, particularly the Wonder Wild cards are comprehensive in relation to the structure, content and questions. According to Thabane et al. (2010), a pilot study is a very small study which takes place prior to the actual study so as to unearth the potential difficulties that may arise in the larger study and use it as a learning step in facilitating the preparation and launching of the actual study. A list of crucial criteria was established to ensure that all aspects were observed and considered when conducting the pilot study, these aspects cited from Barriball & While (1994) include:

5.4.1.1. the language used in the interview guide and research instrument
5.4.1.2. awareness of any bias
5.4.1.3. awareness of any errors including typing errors
5.4.1.4. suitability of questions for children
5.4.1.5. suitability of questions for teachers
5.4.1.6. suitability of research instrument for teachers
5.4.1.7. suitability of research instrument for children
5.4.1.8. the sort of responses the research instrument will elicit
5.4.1.9. identification of any challenges that may arise or any weaknesses
5.4.1.10. structure of interviews and focus groups to ensure cohesion and flow
5.4.1.11. openness to emerging concepts
5.4.1.12. performance of interviewer when conducting interviews and focus groups
5.4.1.13. any changes and adjustments to be made

All the above aspects were considered so as to verify the use of the interview and focus group guides, together with the research instrument (i.e. the Wonder Wild Cards) and to establish validity by considering all the above implications of the study and how these might influence the data collected. Notwithstanding that pilot studies were conducted to prepare for unexpected contingencies that may arise during qualitative data collection, the pilot studies in this research were mainly conducted to check the feasibility of the research study, particularly the use of the research instruments and the quality of data that they foster.

The pilot study was conducted a few months prior to the commencement of the fieldwork during an unprecedented pandemic of the Covid-19 in which schools were temporarily closed for the remainder of the scholastic year. As a result of lock down measures, all pilot fieldwork was carried out remotely using online platforms such as Zoom. This allowed the researcher to record audio as well as share the cards on the screen for the participants to discuss. However, this was not without its challenges as one of the main challenges in the pilot study was recruiting participants, especially child participants that are still gaining mastery of usingthese online provisions for remote learning and long distance communication. In addition tothis, online communication with the researcher with whom they would have never been in contact face-to-face would have been rather daunting for the young participants.

Consequently, the provisional focus group with children had to be replaced with an interview carried out with a child a year younger than the specified age of the participants. In spite of this, the interview with the child participant was conducted to explore whether the cards are suitable for children in terms of the language used, the stimulus expressed in each card, the feasibility of the questions and the sort of responses elicited.

Two pilot interviews were conducted with teachers from two different schools and different teaching experience. The first interview was carried out to establish whether there were any changes to be made to the research instrument after its first trial. One concern with modifications after piloting the study is that in light of the recent findings, data can become inconsistent when trialled again or when doing the bigger study. In conforming to this, a second interview was carried before completion of the pilot studies so as to trial the research instruments/ interview questions if any changes were made during or after the first pilot interview with the teacher. The aim was to ensure construct validity in research instruments and track any changes prior to attempting at fieldwork. The interviews were also carried out to ensure the suitability of the research instrument/interview questions for teachers and acknowledge any further probing questions that might be essential in delving deeper in the participants' responses.

A pilot focus group was later conducted with six PGCE beginning teachers. The intention of conducting this focus group with beginning teachers was to test philosophical dialogue as a method and find out what type of data could be collected. The beginning teachers were chosen as they are a population similar to the target population (practicing teachers). The research methods and instruments were thus assessed in terms of how feasible they were to be used with children and teachers.

A substantial assessment of the methods and instruments was conducted by completing the questions listed earlier on by Barriball and While (1994), which helped to identify what worked and what didn't in the pilot studies conducted. The table below shows an evaluation of the pilot studies supporting the quality criteria of qualitative research from Barriball and While (1994).

Quality criteria	Evaluation of pilot studies	Changes made to meet quality criteria

LANGUAGE	Language was coherent and understood by all pilot study participants including children	No changes to language was made
TYPING ERRORS	Typing error was noted in card no. 6	Typing error was amended after the first pilot interview
SUITABILITY OF QUESTIONS FOR CHILDREN	Questions were understood well and were considered appropriate for use with children, however further probing questions might be needed to encourage in-depth thinking and more detailed responses.	
SUITABILITY OF QUESTIONS FOR TEACHERS	Questions were understood well by both teachers and student teachers in the pilot studies. Both focus group and interviews enabled participants to explore the subject in detail. A variety of responses were obtained. Questions seemed to flow well within the focus group and interview guide. A need for further prompting was identified, however each pilot study introduced new prompts.	Introducing prompting questions to engage participants in deeper discussions, for example; is there anybody who disagrees with this? Why?
SUITABILITY OF RESEARCH INSTRUMENT FOR CHILDREN	The child in the pilot study was able to answer the questions and give reasons for their response.	No changes considered
SUITABILITY OF RESEARCH INSTRUMENT FOR TEACHERS	The two pilot interviews carried out with teachers as well as the focus group carried out with PGCE students all demonstrate that the set of cards, 'Wonder Wild' encouraged teachers to provide responses which opened various discussion points. During the interviews and focus group conducted, participants expressed that they have enjoyed participating in such discussions and reported that using animals in the research instrument made it easier to argue and discuss	No changes considered
RESPONSES RESEARCH INSTRUMENT ELICITED	The methods piloted (animal cards, interview and focus group questions) resulted in rich data. Participants reported different views of science along with some shared knowledge and ideas about the way science works.	No changes considered
CHALLENGES AND WEAKNESSES ANTICIPATED	Due to the amount of cards present in this set, one of the main challenges anticipated for this study is the time dedicated for each interview and focus groups. Pilot interviews were carried out within the stipulated time	To keep focus groups concise in order not to exceed the time stipulated and to ensure participants'

	and within the stipulated interview schedule, however from the pilot focus group conducted, it was foreseen that due to the nature of the focus group and the subject areas to be covered, time constraints were going to be an issue. As a matter of fact, the extensive and indispensable discussions that took place during the pilot focus group for each topic or card discussed, suggest that not all the cards might be used for each and every focus group. For this reason, if not all cards are covered during a focus group, participants will be asked to choose a card which they would like to discuss.	most important ideas were prioritised, researcher asked participants to choose the cards from the Wonder Wild Cards that speaks out to them the most and discuss. This also helped participants in establishing relationships between cards through their arguments.
STRUCTURE OF FOCUS GROUP AND INTERVIEWS	As specified in the point made above, during the pilot interviews the schedule went ahead as planned. However, with the pilot focus group, the three last cards had to be eliminated to keep the focus group an hour long. No priority was given to particular cards. The cards were used in succession. A logical structure was evident in the flow of both interviews and focus groups. This was evident in continuous discussions in the pilot studies.	Due to time limitations the structure of the group might vary in terms of the content covered. In such cases participants will be asked to choose a card which they would like to discuss further.
OPENNESS TO EMERGING CONCEPTS	After analysing the pilot study results, a set of emerging categories were identified which showed the extent of discussions in both focus groups and interviews. The emerging categories are discussed further in subsequent sections within this chapter.	Focus groups showed more openness to emerging concepts as a result of the depth of the discussions.
PERFORMANCE OF INTERVIEWER		Attention to flow of argument and prompt probing questions needed.

Table 5.5.1.: Quality criteria evaluation of the pilot study

5.4.2. Recruitment and sample

The participants in the study were 51 children from year five (9-10 year olds) recruited from three primary schools in Malta and 11 primary school teachers from seven primary schools across different Maltese regions. Year 5 Maltese students (aged 9-10 years) and their teachers were seen to be well-suited to provide a common understanding of older primary school children's understanding of science. Primary school students remain under-researched when it comes to nature of science and thus, this study was aimed at involving younger learners to reflect and share their ideas about aspects of nature of science in a stimulating way.

Initially, the design of the study was aimed at recruiting participants through convenience sampling by choosing primary schools from the southern region of Malta. However due to the Covid-19 pandemic some changes to data collection had to be made to accommodate new regulations and school policies. Schools from the southern region of Malta were initially invited to participate in the study prior to the start of the school year. Four schools were initially recruited. As a result of the safety measures and new protocols, face-to-face data collection was not permitted and as a result two of the schools withdrew their consent to participate.

A purposive sampling strategy was used to recruit schools from different regions of Malta. Foreseeably, recruitment was exceptionally challenging, with most heads of schools hesitant to participate in such a time of uncertainty and with new regulations in place. Over twenty-five schools were invited to participate from across all regions of Malta. Only three schools in all gave their consent to participate, these included a school from each sector: state, catholic and independent. Schools were recruited from two different regions of Malta: two schools from a town in the southern region of Malta and a small school from a village in the north-western region of Malta. A total of fifty-one children gave their consent to participate.

Despite an open invitation for teachers to participate, only the classroom teachers of participating students took part in the study. As a result, teachers were also recruited through convenience sampling by acquaintance to the researcher as well as through snowball sampling as a means to bring together a group of teacher participants for focus group participation in after school hours. A total of eleven teachers were recruited; four teachers were recruited from schools (those being the classroom teachers of the participating students) and seven other teachers recruited through convenience and snowball sampling.

Two classroom teachers were interviewed individually, however two teachers from the same school were interviewed together after school hours. Interviews were conducted with teachers instead of focus groups due to teacher shortage and availability. The remaining seven teachers were divided into two focus groups; one of three and the other of four participants. Table 5.1. below shows the way in which recruited participants were organised, together with the number of focus groups conducted from each school.

All children from the (9-10 year olds) were invited to participate. Most schools had one or two classes. Prior to the focus groups with children, teachers identified which children gave their consent to participate. Children who were present all had written consent from parents.

Type of School	*Number of Schools*	*Number of Children*	*Number of focus groups*	*Number of teachers*
State	1	12	1	1
Independent	1	21	3	1
Catholic	1	18	2	2
Teachers	0	0	2	7
Total	3	51	8	11

Table 5.5.2: Summary of research participants

For the scope of the research, only fifth grade students (nine to ten year olds) and primary school teachers were considered. The sample above reflects the specified characteristics for the study, including recruitment of different types of schools; catholic (girls only), state (mixed boys and girls) and independent (mixed boys and girls), and within different demographics. Different types of school dynamics and demographics allow for some differences in language usage, for example, independent schools are commonly English speaking, whilst state schools predominantly feel more comfortable speaking Maltese. Allowing for these dynamics does not only represent the bilingualism of the Maltese population, it may also allow for richer discussions.

Out of the seven primary school teachers selected through convenience sampling, four are from state schools, two from Catholic schools and one from an independent school. The teacher participants of this study are all in-service teachers with a minimum of three years' experience teaching primary school science as part of the Maltese curriculum. im

Only one independent school teacher from the eleven participating teachers is specialised in science education. The remaining ten teachers with a Bachelor in Primary Education, reported that apart from their personal schooling, they had no experience or knowledge in teaching science, with the exception of two educational modules about the pedagogical aspect of teaching science completed during their initial teacher training. No male teachers were recruited due to the shortage of male teachers in primary schools.

5.4.3. Using interviews and focus groups to explore a collective understanding of NoS

Interviews and focus groups are sensitive in reflecting the way social groups attach meaning to a particular entity in society (such as science). Interviews are a conversation, a negotiation of meaning between the researcher and the participant (Roulston, 2014). Interviews are at a favourable position in producing objective social reality based on the reflections made by participants and their meaning-making (Brinkmann & Kvale, 2018).

Focus groups are on the other hand, a group of participants brought together "to discuss and comment on, from personal experience, the topic that is the subject of the research" (Powell & Single, 1996, p. 499). As an interactive group discussion, focus groups are aimed atobtaining a range of views from a social group (Nyumba et al., 2018).

The presence and engagement of participants is of great value in gaining access to collective knowledge. Focus groups remain favourable for gaining insight into a social group's thoughts, beliefs and ideas. This is especially true of qualitative studies aimed at exploring social representations. Focus groups have been used substantially to provide a collective understanding of social phenomena by means of social representations, such as climate change (Wibeck, 2014), diabetes (Leclair et al., 2009), and fake news (Sh & Ye, 2022).

As noted by Bar-Tal (2012), group members who share similar experiences or have common goals, values and beliefs, may develop common knowledge. For this reason, focus groups can yield great insight when participants are encouraged to express their views and add to, or respond to the views of other group members. This dynamic allows participants to define their worldviews based on the points of view that they share with others (Freeman, 2013). Teachers are one such example of a social group; primary aged children are another.

Focus groups with children

The six focus groups with children were aimed at producing data that might not have otherwise been available if collected from a single respondent. Focus groups are meant to lead to a wider range of views and ideas due to their interactive nature, and offer more insight than individual methods such as interviews (Krueger & Casey, 2015). Kitzinger, Markova & Kalampolikis (2004) state that focus groups are most favourable in acquiring suitable data for social representations as social representations are centred on communication between people within a society.

Focus groups are considered to be the most apt at offering in-depth insight both at the cognitive and the social presence of participants (Nyumba, 2018). From a cognitive perspective, participants are able to make sense of nature of science through thought, reflection and discussions. On the other hand, the social presence can be felt in the interaction of the group and the projection of personalities amongst group members. Thus, focus groups allow for a deep and meaningful appreciation of children's and teachers' social representations of science.

It is for the aforementioned reasons that focus groups were seen to be an appropriate method by which social representations can be explored. Guest et al. (2017) compared the use of interviews and focus groups in a randomised trial and found that focus groups produce more information than what could be captured from a single participant and the data generated provides a wider range of views and ideas. Similar findings were presented by Krueger and Casey (2015) who stated that focus groups can produce more insight than individual methods.

A three-step inquiry-driven process presented by Rinkus et al. (2021) was used in both focus groups and interviews with teachers. This process included;

i). Time for participants to reflection on different accounts of philosophy of science as presented using Wonder Wild cards as a stimulus.

ii). Individual responses to the statements and questions on the Wonder Wild cards, with the researcher asking for reasons for their position.

iii). Engagement in discussion with peers (or in the absence of peers, with the researcher) to elaborate on differences and similarities between views; exploring alternative positions and ideas, proposing new insights and connecting ideas together through talk.

A schedule was written up to cover the questions prior and post the philosophical questions covered in Wonder Wild cards (discussed in section 5.4.4.). The first questions were general questions about science initiated to draw in the participants into the research study (Cohen et al. 2007). Such questions included; "What is Science?' and "Is there a difference between the science you do in school and real science?" The pre and post questions were developed as a framework to complement the concepts covered within the dialogue and clarify further into the differences when comparing how science is done in general with how science is done at school. This is to gain insight into the participants' value of science, what it means to them and how they understand its function within society. The closing questions, such as "Is there a view of science that you agree/do not agree with? Why?" These questions were intended to summarise the main points of the arguments and provide any feedback.

Given the philosophical nature of the question cards, methods for facilitating philosophical dialogue were used in the focus groups and interviews. This approach is outlined in the next section.

Focus groups and interviews with teachers

The two interviews conducted with teachers were chosen for practical reasons due to limitations of access to groups of children at a given time. While social thinking is commonly activated through group discussions such as focus groups, interviews are still commonly used to explore social representations. The theoretical assumption for the interviews within this study is one in which interviews are seen as co-constructed by the researcher and the interviewer.

While semi-structured interviews still have the potential of highlighting the importance of participants to talk about and question their views, beliefs and attitudes about a certain topic (Ritchie and Lewis, 2003), there were some notable differences between focus groups and interviews conducted in this study. Interviews still had the capacity to present descriptions, explanations and evaluation, "a process through which knowledge about the social world is constructed in normal human interaction" (Ritchie and Lewis, 2003, p.138), however, there were some limitations with philosophical dialogue as a result of limited interactions and shared ideas.

The lack of interaction in interviews may in itself produce more surface data in comparison to focus groups. Further probing questions from the interviewer may inhibit coverage of further ideas which focus groups would have otherwise covered when participants tackle each other's arguments from different points of view and in different tangents. To mitigate this, both interviews and focus groups made use of open-ended questions, encouraging philosophical dialogue through participants' reflections on their worldviews and all that encompasses it, including thoughts, ideas and beliefs. To keep interviews and focus groups homogenous, both focus groups and interviews used a very similar structure. Firstly, the same research tool; Wonder Wild (which will be discussed in the next sections) was used. Furthermore, to generate in-depth insight in both focus groups and interviews the same three-step inquiry-driven process presented by Rinkus et al. (2021) was used in both focus groups and interviews with teachers.

While a community of inquiry approach as presented above is commonly used with focus groups (where there is interaction), one-to-one discussions can make use of the above process for participants to develop their own ideas about NoS. The role of the researcher and in this case the facilitator adapts according to the method of research adopted, with the additional role of making sure that everyone has a chance to speak and respond to eachother. For this reason, in both interviews and focus groups, the role of the facilitator/ researcher is to question, prompt alternatives, propose new ideas through the philosophical statements and questions presented, and aid in the connection of ideas. With focus group discussions, the role of the researcher/ facilitator changes to accommodate the needs of the group. In this case, the researcher facilitates discussions by introducing a stimulus for discussion and prompting further discussions through prompting questions.

5.4.4. Philosophical dialogue as a research method

What is novel about the methodological approach in this study is that philosophical dialogue is used as a method by which focus groups are conducted, as a way to elicit and explore teachers' and children's social representations. Within this study, dialogue is referred to as a process of meaning-making which is made possible through interaction and communication in a group setting.

> *[Dialogue] will make possible a flow of meaning in the whole group, out of which will emerge some new understanding… this shared meaning is the 'glue' or 'cement' that holds people and societies together.*
>
> (Bohm, 2013 p.2)

What is philosophical dialogue?

Philosophical dialogue is an inquiry-based discussion were participants share ideas, beliefs and perceptions about a common topic (Nishiyama, 2018). Through dialogue participants are able to share their lived experiences, listen to a variety of thoughts, refer to their own thoughts through reflection, offer reasons, and question their own thoughts, as well as that of others (Nishiyama, 2018). Dialogue is philosophical in that it carries philosophical judgements that represent the beliefs, ideas, experiences and perceptions of the participants (Kennedy, 2010, Nishiyama, 2018). The foundation of philosophical dialogue is the act of speaking and listening to each other, creating a capacity for shared thinking. Epistemologically, philosophical dialogue presupposes that knowledge is constructed through social interaction and is constantly reconstructed (Nishiyama, 2018). This suggests that ideas, beliefs and perceptions are created and validated by the group and replicated within each member of the group.

Philosophical dialogue is usually initiated with a stimulus which can be in the form of visuals or questions and built on collaboration and sharing of philosophical views and ideas in a group (Kennedy, 2010). Dialogue as discussed in Fisher (2007), pertains to a form of talk which is exploratory in nature, tentatively dependent on the sharing and exchange of ideas about the concept being discussed. Speaking and listening helps children to think and discuss what they think with others (Kennedy, 2010). Through dialogue, participants are able to verbalise conscious thoughts and develop conceptual skills for their own understanding.

Why is philosophical dialogue useful as a research method?

Conventional research methods such as traditional interviews and focus groups are not always attuned to the demands of current research (Schwartz-Shea & Yanow, 2012; Nishiyama, 2018; Golding, 2015), especially in exploring social representations of children and teachers about a philosophical and epistemological topic. Four reasons are presented for this; i). the in-depth reflections that are possible with philosophical dialogues, ii).it gives participants the opportunity to actively seek the meaning behind their reflections and that of others, iii). helps in looking at concepts which are unclear and debatable, v). allows space for participants' voice (Golding, 2015).

The first reason for a philosophical approach to conducting interviews and focus groups is that philosophical dialogue aims for participants to explore the meaning behind their reflections and helps reconstruct ideas and beliefs at the collective and individual level (Fisher, 2007). This helps participants to explore alternatives, propose new thoughts and ideas, connect their ideas together and distinguish better ideas from good ones through reasoning and reflection (Kennedy, 2010).

Furthermore, focus groups and interviews which use philosophical dialogue as a research method looks at the hidden assumptions that participants have about a topic (such the nature of science), allowing for a thorough understanding of the participants' ideas, beliefs, thoughts and perceptions through the construction of meaning both at an individual and collective level (Lam, 2015). Thus, social interaction thus serves as a medium by which the assumptionsof nature of science presented by the participants' are uncovered.

> *The ideal immediate goal of a dialogue is for the participants to arrive at one or more reasonable philosophical judgements regarding the questions or issues that occasioned the dialogue*
>
> (Gregory, 2007, p.161)

Participants in focus groups are invited to make judgements based on the discussions and the ideas that will come out from the focus groups. The philosophical dialogues are therefore critical in stimulating thinking and reasoning capabilities and challenging participants into different views, giving them the appeal to reason and be aware of one's thoughts. Thus, philosophical dialogue was seen as relevant and applicable to be used in focus groups with children to stimulate interesting discussions about NoS.

How is philosophical dialogue used in focus groups?

Philosophical dialogue takes the form of a philosophical inquiry sustained by dynamic interaction between children over a specific stimulus such as a question (Alexander, 2006).

Focus groups in this study were initiated and supported by Wonder Wild cards which aimed at developing interesting philosophical dialogue surrounding different NoS concepts directly taken from literature on NoS. The philosophical questions provided in this research instrument aim to disclose their philosophical positions and arguments rather than just as a means of elicitation. In virtue of doing this, it invites evaluative interpretations rather than responses to questions, where children can build and develop their own ideas in a social environment.

Focus groups can use the model of inquiry presented by Kennedy (2010) which is formed of seven steps

i. Participants sit round in a circle facing each other
ii. A stimulus is given which could be an image, story or video. The stimulus aims at engaging the participants to discuss the topic of interest
iii. The researcher acts as a facilitator by asking participants about the stimulus
iv. Participants are encouraged to contribute by replying to each other's statements, saying whether they agree or disagree, and why
v. Participants are free to bring in their own personal experiences in their discussion to identify reasons for their agreements or disagreements
vi. The facilitator prompts participants to discuss further or add to their previous statements, such as, "why do you think that?", "What do you mean?", "Can you tell me more about this?"
vii. The end of the philosophical dialogue does not mean that a conclusion or consensus has been reached

Philosophical dialogues in this study were initiated and supported by the use of Wonder Wild cards as a research tool that prompts philosophical discussions based on the philosophical questions presented. The philosophical questions provided in this research instrument aim at disclosing participants' philosophical positions and arguments rather than just as means of elicitation. In virtue of doing this, it invites evaluative interpretations rather than responses to questions, where children can build and develop their own ideas in a social environment. The idea is built on encouraging opinions rather than simple responses.

As a means to accommodate to an online setting, Wonder Wild cards were shared on the screen and displayed on the interactive whiteboard in the classroom. Further mitigations were considered in preparation for the online dialogue, including having the teacher or classroom teaching assistant present to be able to facilitate the dialogue further when necessary.

All community of inquiry approaches, such as philosophical dialogue, require three important considerations; that the dialogue is well-reasoned, well-informed and personally meaningful. This means that “the person making the judgement has found his/her own way to it” (Gregory, 2007, p.161).

Moreover, Gregory (2007) acknowledges that philosophical dialogue permits participants to be clearer in their thinking, allowing for self-correction. However, he also mentions that individual thinking is still susceptible to error and thus communal dialogue is strengthened by a thinking community. This means that individual ideas have prevailed the communal dialogue. For this reason, using a philosophical and social approach to focus groups, does not only strengthen a deeper level of thinking, it holds participants accountable to their thinking.

5.4.5. Wonder Wild as a philosophical research tool

As a stimulus for philosophical dialogue about science, Wonder Wild was created. As will be addressed within this section, the research tool consists of a set of eight cards with each card addressing a key philosophical idea from chapter two of the literature review. The cards each have three related prompting questions that are drawn from the key idea itself. A full copy of the cards can be found in appendix ii.

This study draws from philosophy of science both from its theory and methods by inviting children and teachers to participate in thought-provoking ideas from philosophy of science through dialogue. Philosophical dialogue (refer to section 5.4.3.) was selected as a research technique to actively engage children to discuss and share their ideas in cohesion with their social group to identify children and teachers’ social representations of NoS.

When using a community of inquiry approach such as philosophical dialogue, a stimulus might be used to stimulate thinking and sharing of ideas. Visualisations are being commonly used, even in science education, to enliven children's ideas in dialogue. De Schrijver and Cornelissen (2016) have used a set of cards represented by different animals to stimulate children to discuss philosophical questions related to scientific concepts and technology in their project 'Philozoo', questions such as: '*Is an apple alive?' and 'Can a rabbit be a scientist?'.* A similar structure to Philozoo is the Wonder Ponder philosophy based on a set of philosophical questions to engage children in open discussions about different topics such as Christmas and gift-giving. Such resources are intended to be thought-provoking and a fun way to engage children in-discussion about various issues within society. Sourcing such initiatives in philosophy with children, thought-provoking cards with open-ended inquiry is a novel idea to get the children to discuss big and challenging ideas that are often given less importance in the curriculum. This study uses question cards designed specifically to explore nature of science, based on ideas from the philosophy of science.

Wonder Wild cards were designed as a friendly stimulus for children and teachers to open philosophical discussions centred on the several challenging issues of nature of science. Mainstream accounts of western science were drawn up from several sources including Chalmers' (2013) to identify some of the main ideas that have commanded attention and enquiry throughout the years, these include issues of demarcation (boundaries between what science is and what it is not), truth and reality (identifying possible bias, issues of subjectivity and expertise) and processes of science, amongst others. The main ideas exposed in the mainstream accounts of science were compiled as big philosophical questions that stress the challenges faced by science (see table 5.4.5.).

From reviewing the literature, mainstream philosophy of science is identified as being highly male dominated, white and European. Due to this, the philosophy presented here can reflect some limitations to the ideas presented on how science works and how knowledge claims are justified. However, the openness of the questions and the use of philosophical dialogue means that these positions are presented as open to challenge and critique. However, the openness of the questions and the use of philosophical dialogue means that these positions are presented as open to challenge and critique. The design of the cards was entirely based on the philosophical ideas, their concepts and the responses developed from these ideas of science, rather than specific schools of thoughts such as positivism and relativism. Thus, ideas brought on from different accounts of philosophy of science were compiled.

5.5. Philosophical grounding of Wonder Wild

In this study, Wonder Wild was used as a research instrument dedicated to find out what children and teachers think about science. It is a set of eight cards each inspired by big ideas discussed in philosophy of science in chapter two. Each card includes a statement with the philosophical idea which is quoted by an animal and three discussion questions to help children explore that particular idea. Such questions are aimed at encouraging deeper thought and discussion about nature of science.

Animals are used to neutralize any misleading associations centred on what a scientist or 'a person doing science' would look like, or any bias related to gender of people or scientists. The cards aim at minimising any bias and unhelpful assumptions that might jeopardise philosophical thinking. Animals are presented as cartoon illustrations for them to be child friendly, colourful and inviting.

Eight cards were seen as a feasible number to compile the key philosophical ideas compiled from philosophy of science literature (see chapter 2). The ideas and questions that follow have the ability to prompt participants to discuss different concepts of NoS such as construction of scientific knowledge and certainty in science. The different concepts of NoS which may proceed from the discussions, as well as the content of the cards and reference tophilosophical ideas taken from the literature review are illustrated in the table below.

CARDS	PONDERING QUESTIONS ON CARDS	REFERENCE TO IDEAS FROM PHILOSOPHY OF SCIENCE	CONCEPTS OF NOS
LEO THE LION	1. Where do we get our knowledge from? 2. Are there any similarities or differences between science and other disciplines/subjects? (How can we tell of something is science or not)	Scientific knowledge is built on sense experience	• Demarcation of science • Scientific methods • Critical testing • Certainty • Construction of knowledge

	3. Do we only believe what we can observe?		
BAO BAO THE PANDA	1. Do we always follow Bao Bao's way of doing science? 2. Do we only get our knowledge from science? 3. How many times does something have to work to say it is true?	Science is discovered from experimentation and observations	• Scientific methods • Scientific proof • Demarcation of science • Certainty in science • Critical testing • Limitations of science
SKY AND TWIGA THE GIRAFFES	1. Do you think that every idea can be proved wrong? 2. What happens when something is proved false? 3. Should scientists set out to try to prove their ideas wrong? Why?	Science can be falsified	• Critical testing • Scientific methods • Certainty in science • Science and predictions • Demarcation of science • Scientific proof
ELMAR THE ELEPHANT	1. Is everybody's idea as important as everyone else's? 2. When idea in science is replaced by a new one, is the new one always better? 3. Why do you think scientists see different things? What effects does this have on science?	Science develops through paradigm shifts	• Collaboration in the constructs of knowledge • Limitations of science • Interpretations • Scientific expertise • Progression in science
HARRY THE BEAR	1. If lots of people believe in the same thing does it make it more true? 2. Are all ideas important? 3. Whose ideas should have more weight when talking about science?	Scientific truth lies in power	• Progression in science • Scientific expertise • Limitations in science • Scientific proof • Science and predictions • Certainty in science • Scientific methods

			• Collaboration in the constructs of knowledge • Interpretations
TOBY THE MOUSE	1. Is there a particular way (method) of doing science? 2. Is there something that science can't do? 3. Can science investigate everything?	There are lots of ways to do science	• Scientific methods • Scientific expertise • Critical testing • Limitations of science • Critical testing • Interpretations
AZRA THE ZEBRA	1. If something was always true in the past, does it mean it will always be true in the future? 2. What type of things will/won't? 3. When do we decide that something is not true anymore?	Science is a series of predictions	• Science and predictions • Certainty in science • Scientific proof
BONNIE THE MONKEY	1. How do our experiences influence what we study and how we study things? 2. Does everybody see the world in the same way? 3. Do we study animals the same way we study human beings or even the materials around us? (think about different tools and ways of studying all these things).	Scientific knowledge is relative to time and space	• Interpretations • Certainty in science • Collaboration in the constructs of knowledge • Limitations of science • Scientific expertise • Progression in science

Table 5.6. Summary of Wonder Wild cards

The central focus of the cards is inquiry into the 'pondering questions' presented on the cards. Participants reflect on the card, discuss the idea presented, share understanding between participants on the idea or concept. The questions are intended for children and teachers to ponder on the nature of science, and to stimulate argumentation about the idea presented, and to question in a supporting environment their understanding and that of others. The use of open questions allows participants to draw on any knowledge and experience they think relevant. This is a distinctive approach as other studies on NoS have tended to assess students' understanding in a limited range of contexts (such as subjectivity, tentativeness andsocial and cultural embeddedness of science to name a few).

As can be observed from the table above, the first card is related to a view of science whereby scientific knowledge is derived from experience, specifically sense experience. Such a card is useful to instigate discussion on the role of observation in scientific research and on the origin of scientific knowledge. Participants are encouraged to agree or disagree with the statement put forth and provide a justification for their view. While the card is mainly targeted at inviting discussions on where knowledge comes from, and whether observation is the method by which scientific knowledge is attained, the card it also aimed to invite discussions on the demarcation problem of science (what constitutes as science and what does not constitute as science).

The second card aims at eliciting participants' ideas about the process of science and its methods. Participants are invited to agree or disagree with the animal (panda) that suggests that science follows a certain rule or method. The aim is to draw on children's experiences of doing science, how they think scientific knowledge is achieved, how results are tested, and what encourages scientists to come up with scientific ideas. The main philosophical idea is to think about the practice of science and inquire into different processes of science and their criteria of quality. The points of discussion relevant to quality in science include: validity, reliability, replication of methods and evidence. While these concepts might be difficult for younger participants, facilitation through questioning, such as, "How many tries does it take for scientists to ensure that they have the right answer?" or "Should a scientist try to see if another scientist is correct? It was also considered appropriate here to draw-in children's and teachers' ideas based on their experiences of 'doing' science in science education and how this reflects practices carried out in actual science.

The third card encapsulates the idea of falsifiability, both in terms of a method or guideline of science as a discipline, as well as in terms of the characteristics of science that might be attributed to it as a result of falsifiability; such as tentativeness of scientific knowledge. Here participants are encouraged to reflect on the type of knowledge that science produces. Critical evaluation of such a philosophical idea can prompt dialogue on the limitations of science in terms of the way science is studied, its values and development of knowledge.

The fourth card is indicative of the idea of complexity in the process of science. In contrast to the previous three cards, the fourth card presents an alternative idea, questioning the process of science. The card depicts science as an elephant-sized puzzle to give credence to the idea of different contributions within science and how together these scientific contributions add to scientific knowledge. This card is also responsible for encouraging participants to enquire about the distinction, if any, between beliefs and truth and whether beliefs constitute knowledge. Participants are invited to discuss in depth how science works and how scientists contribute to scientific knowledge. The idea of objectivity and subjectivity of scientific knowledge might also be questioned here.

Building on the fourth card, the fifth card explicates the idea of a scientific community and power in numbers; enquiring into scientific expertise and confirmation bias. Similar to the previous card, discussions on quality of knowledge and belief are also encouraged here. Participants are prompted to share ideas on whether scientific truth lies in power and thus whether certainty is assumed with repeated testing and confirmation.

As the referring quote being represented in the sixth card suggests, "There are lots of ways to do science", participants are thought-provoked into meticulously reflecting on the opposing view of the second card presented in the pack. Participants are invited to discuss which sort of view/s they seem to consider.

The card thus aims at giving a contrasting view to the second card which suggests that there is a system in place for doing science. The aim here is for participants to critically think about contrasting ideas between philosophers of science and in light of this, reflect on their own ideas about the process of science. This will make clear the participants' thoughts on how science operates in society.

The concept explored in the seventh card is perhaps more difficult to comprehend, especially for younger participants. Probability does featured in the curriculum until children are in secondary school. This card aims at encouraging discussions central to the ideas of prediction and results in science. Participants are prompted to discuss concepts such as certainty in science and whether science can predict future events and if so, how it is able to do that. Pondering questions also enquire into ideas on whether scientific knowledge is constructed based on chance encounters. This aims to gather learners' opinions on certainty in science, scientific expertise, the concept of decisions in science and whether there are any scientific ideas that cannot in fact work within a probability framework. This view centres on children's ideas of truth and knowledge, such as their ideas about the possibility of something to be true based on past occurrences/events. This card can be linked to the idea of fair testing discussed in the second card of the pack. Learners can refer to both cards to enquire into the tentative and progressive nature of science; how scientists' ideas may change and whether results may change if the method being used to collect the data changes.

The last card explores whether truth in science can ever be achieved. This card questions whether science is a process in which people with different experiences come together to make sense of the natural world around them. Discussion central to the question are: "what do we mean by truth?" "how do we know whether something is true or not?" "who decides if something is true and whether there is a correlation between truth and belief?". Furthermore, the subjectivity involved in observing the natural world is questionned, together with with how different scientific ideas work, and how these might have an influence on methods and results.

As a pack, these cards are designed to stimulate learners' thinking skills and engage them in a well-rounded dialogue about nature of science. Such an approach is aimed at exploring the sort of ideas that children have about NoS concepts, for example how it works and the kind of knowledge it produces. The aim of this research tool is to provide participants' with a structure for dialogue and to stimulate thought and reflection on nature of science. The cards can also be a wonderful addition as a classroom resource to explicitly teach or hereby to encourage dialogue about nature of science in science education. More significantly, they can be used as a tool for researchers interested in learning more about people's ideas about science.

The cards were introduced to children and teachers individually in succession starting with the first card. As mitigation for time limitations in two focus groups with children, some cards had to be excluded and therefore, children (as a group) were invited to choose one card (from the last remaining cards).

Focus group discussions and interview discussions lasted approximately an hour long and were recorded. All transcripts were analysed to identify social representations.

5.6. Analysing philosophical dialogues using a structured approach to social representations

The theoretical framework applied for the analysis of this study is a dual function process of anchoring and objectification, as termed in Moscovici (1984). Anchoring and objectification work together to provide meaning about the subject (NoS), explain how ideas are communicated and how they are transformed into familiar contexts. The theoretical framework is applied to the analysis of this study to shed light on the development of social representations of nature of science and why such social representations of science exist amongst the social group. Through the process of anchoring and objectification the study aims to:

Anchor

This process is particular in making what is unfamiliar to something which is familiar. This was done by analysing the patterns of thinking through embedded language when 'talking' about science. For this reason, data was critically analysed to look for familiar elements that locate thoughts, ideas and images of science. Secondly, data was also subject to thematic anchoring which aims at mapping similar images or thought patterns to existing ones. For example,

Objectification

Objectification, as a process, involves transforming abstract ideas into tangible forms. It manifests ideas as concrete phenomena. As a more active process, objectification represents the specific examples or contexts that children and teachers use to contextualise their thoughts and ideas into something that can be understood and discussed. As an example, children may use contexts from school science such as gravity to explain different meanings of observational phenomena in scientific activities.

Data from children's and teachers' philosophical dialogues were transcribed and analysed using a social representations framework. Sentences from transcripts were read and coded using a structural approach. A structural approach is one way to help identify social representations from dialogue by analysing the relationships between participants' mental cognitions and the similarities between them. This means that a structural approach looks at how a social representation is structured and thus how a social representation is identified.

The structural approach to social representations was first employed as a methodology by Abric (1994) who suggested that each social representation has a structure consisting of the main themes within the data and the inter attributes that characterise and link the main themes. Such a structure represents how the social representation came into being. The structural approach of social representations was presented as a method of analysis by Jung,Pawlowski and Wiley-Paton (2009) as a process of three steps which comprise of; i). Contentanalysis, ii). Similarity analysis and core/periphery analysis, iii). Correspondence analysis.

Content Analysis

Content analysis was used for initial coding to identify the main ideas in participants' dialogue.An open coding method was adopted to explore the content of individual statements presentin dialogue (Krippendorff, 2018). This process consisted of translation of text into manageable codes. The codes were then examined for patterns in the content. Using Mayring's (2015) ruleof frequency, a code was allocated to an idea/concept if it appeared at least once across all focus groups and interviews. Words or sentences that imply the same idea were categorisedunder the same code. Coding was done using Nvivo.

The table below illustrates some of the codes applied to transcripts from both children and teachers. No predetermined criteria was used for initial coding, to allow for greater autonomy and flexibility of data, as well as to explore the presence and meaning behind participants' expression of ideas.

Codes from transcripts

- Science is not direct observation
- Scientific knowledge comes from interaction
- Science is interest-led
- Science discovers
- Science is a developing process
- Science as a dialogue
- Belief is a result of evidence
- Science has limitations
- Scientific method is a way of presenting science
- School science is different to science in real life
- Science is influenced by problems in society
- Scientific knowledge comes from experimentation and observation
- Prior knowledge effects observation

Table 5.6. Codes assigned to data

Similarity analysis and core/periphery analysis

Every social representation is made up of at least two elements; one is the core and the other the periphery or peripherals. The core is made up of the main idea of idea/concept, while the peripherals are the characteristics or attributes that link and define the core (the codes from table 5.6.1). An example of the process is illustrated in table 5.6.2. below.

The structural approach to social representations looks at the similarities and differences that are present amongst the content identified through content analysis. After text was analysed into codes and categories, they were then labelled according to qualitative similarity. Codes were compared between each other to identify differences and similarity based on the context of discussion and the way they have been discussed.

Analysis of similarity assumes both frequency of content/topic, as well as topic correspondence. The characteristics of similarity are weighed on qualitative judgments that distinguish between the different statements and categories to identify which statements are more similar than others, which ideas persist in different contexts and which ideas are most frequently discussed. The social representation then becomes an account of the core element which remains stable regardless of context and which contain the frequently discussed idea/s within a topic; and the peripherals, the ideas that change depending on the context and the group. Such type of analysis is respective to the structural approach to social representations in that it aims to look at the similar content in statements to explore the relation between the topic and participants' perspectives and the relation between the different ideas and perspectives present in the data. The latter being accountable for the power of association within the data.

The table below, taken as an example from the teachers' data set, demonstrates the first two processes of data analysis; codes from content analysis together with the context in which they are discussed (peripherals) and the core to which they relate to.

Transcripts	**Peripheral**	**Core**	**Social Representation**
"I think that we believe what we can no longer question…I think you get to the point where you can't question it anymore, you start believing in it to…understand where the knowledge comes from	Belief is a result of lack of knowledge. Belief is something we have when something is beyond our understanding.	Belief is related to the understanding of an individual whether it is through evidence or not.	Science is based on beliefs, but beliefs haveno place in schoolscience.

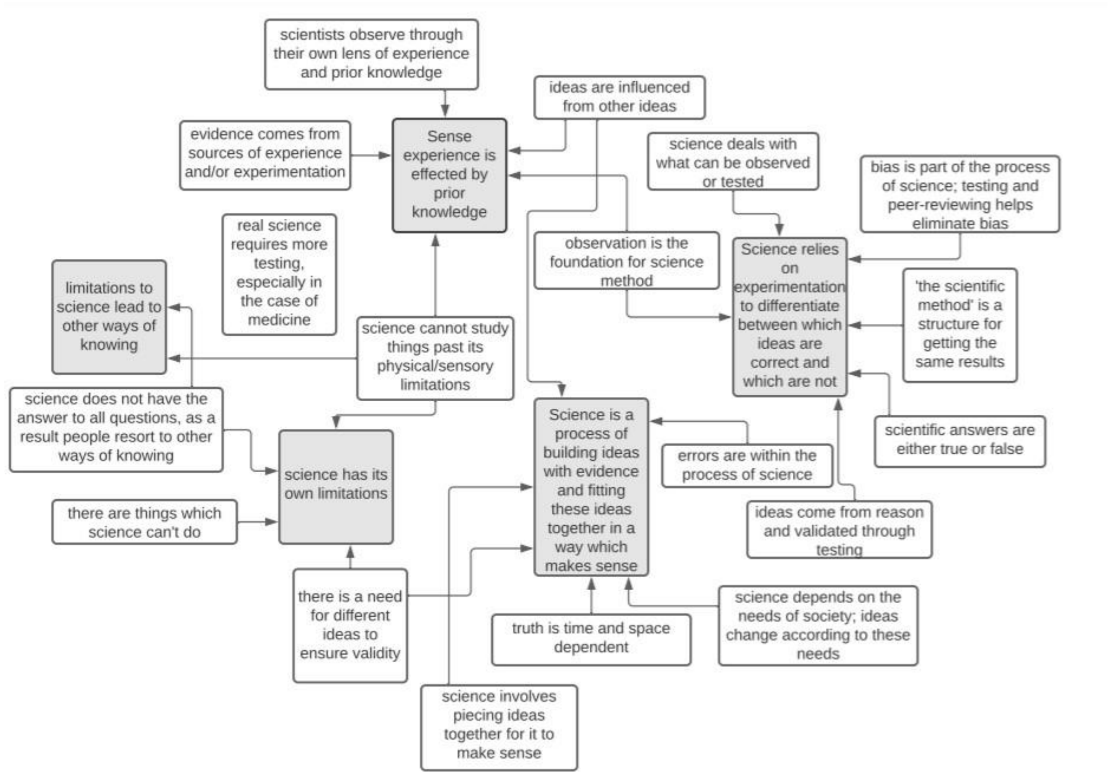
somewhere else, and it empowers you to question it further…which might be why people believe stuff beyond their understanding" (P4) "all scientific knowledge is based on certain assumptions that you have to believe in" (P5) *"I don't know if belief is one word I would associate with science" (P6)*	Belief is not something scientific – not based on evidence.

Table 5.6.2 Data analysis procedure

Correspondence Analysis

Finally, a qualitative correspondence analysis is conducted to help with the understanding of a social representation (Wagner et al., 1999; Smith & Joffe, 2013). The peripherals and cores from the data are studied to identify any similarities between peripheral data and to explore the relationships between the different cores present. For this reason, a map was drawn out where the peripherals were categorised into themes and visually laid out to illustrate the similarities in perspectives. Data was mapped to visually uncover the organisation behind a social representation by demonstrating the relationships and interactions amongst the elements and themes within the data (Sourial et al. 2010).

The character of a social representation can be seen as being of two parts; one part which is static (the core) and the other which is dynamic (the peripheral). The core idea (shaded grey) is highlighted as being the centre which makes up the social representation. The codes (peripherals) are dynamic and thus can be seen to overlap into other core ideas to show the strong link between one core idea and the other. As an example from the figure below, one social representation is 'sense experience is effected by prior knowledge', this is the core of the social representation, however what led to this social representation is a set of peripherals that characterise this social representation, these include 1). Ideas are influenced from other ideas, 2). That scientists observe through their own lens of experience/knowledge and that 3). Science cannot study past its physical and sensory limitations. There is a great deal of overlap amongst some of the peripherals. For example; an overlap can be seen for ‘science cannot study past its physical and sensory limitations’ with the core idea that ‘science has its own limitations’. This overlapping suggests a stronger bond between each core idea discussed in dialogue with children and assigns substantiality to collate to a social representation.



Core

Peripheral

Fig.5.6.3 Diagram of children’s social representations

Arriving to a social representation

Social representations are identified using the core and peripheral data. Each social representation thus consists of a core and its peripheral elements. This means that a social representation is made up of the idea and how it was communicated in dialogue. Each process discussed above; content analysis (codes from data), similarity analysis (similarity between codes) and correspondence analysis (codes mapped to understand similarities) ensures a transparency in the way a social representation is explored.

5.7. Ethical considerations

After attaining ethical approval from the University of York, permission was granted both from the Maltese Ethical Department of Education (MEDE) to conduct research in state schools as well as from Secretariat for Catholic Education (SfCE) for access into Catholic schools.

Several principles of consent were applied to the study including participants' right to withdraw from the research at any time without providing a reason, their consent for data to be used in different research provisions and informing participants on privacy and data storage (BERA, 2018).

Confidentiality and anonymity of participants' data is critical in conducting research, thus, any identifiable data was fully anonymised one week after collection. Despite anonymity being harder to guarantee when data is collected in digital contexts such as through online platforms such as Zoom, all participants within a focus group were signed in through the school account and thus all children's names were withheld from researcher at point of collection. This guarantees full anonymity of child participants.

As stipulated in the General Data Protection Act (GDPR), all data collected for this study was stored in a password protected file stored in the University's drive accessible to only the researcher. Participants were informed of the storage of their data in the stage of consent.

As stated above, data collection and consent complies fully with the ethical guidelines suggested by the University and those stipulated by the GDPR.

Informed consent forms clearly described the implications of the research on participants, including the provisions for audio-recording and note taking during interviews and focus groups. Confidentiality was highly stressed and esteemed throughout the research.

This chapter has described how philosophical dialogue was used as a method for gaining access to children's and teachers' social representations. It has also described the methods of analysis using social representations as a framework. In the next chapter that follows, I will discuss the findings by presenting the social representations of science from children's dialogues.

Chapter 6

Children's Social Representations

This chapter will present the findings from the children's data by addressing the first research question: 'What are children's social representations of NoS?' A total of six social representations were identified from children's dialogue. This chapter will thus be composed of six sections; one for each social representation.

Each social representation is identified by the common knowledge being shared between participants, and complimented with children's voices to support the common statement. As explained in the methodology (refer to chapter five), common statements from focus groups were gathered and classified into the core idea. This is equivalent to themes in non-social representations analysis.

The six social representations identified in the study are a considered a system of common beliefs, values and ideas held by children. The table below illustrates the key social representations evident in children's philosophical dialogue about nature of science.

	Social Representations
1.	Sense experience is influenced by prior knowledge
2.	Science relies on experimentation to differentiate between which ideas are correct and which are not
3.	Science is a process of building ideas with evidence and fitting these ideas together in a way which makes sense
4.	Science has its own limits
5.	Limits to science lead to other ways of knowing
6.	School science as a developed body of knowledge intended for the learning process

As can be noted from the table above, a number of views and ideas were commonly expressed amongst children in focus groups. The table also hints into the key ideas from philosophy of science which children have engaged with the most based on their discussions.

Predominantly, children were keen to discuss the role of experimentation and observation when it comes to science. It is also evident from the social representations, that while children had a very positive view of science and its role in society, they also identified some limits to science on what it can or cannot study. Subsequently, children commented that science is not the only discipline which can study the world, adding that other ways of knowing, such as religion and mathematics, can be just as trustworthy and useful.

Common knowledge seems to exist in terms of children's definition of science and its role in society. On this discussion, the first thing that came to children's minds when they heard the word science was 'experiments'. "It's about experiments and making new things" (School A group 2). The idea of testing as means of studying the world was a commonly held idea amongst participants and a strong link can be seen between experiments and testing of ideas. In fact, children clarified that experiments are one way by which scientific ideas can be tested to identify whether scientific ideas are true or not.

6.1 Sense experience is influenced by prior knowledge

The meaning of observation in science was one which was discussed in all focus groups. Children initially suggested different ways of observing; noting on the need of the senses to be able to observe a phenomena. Children brought examples from observation done in school science to share what can be observed and the way that type of observation can take place.

> *1: We observe the effects of something not just seeing things directly*
>
> *5: We don't always observe just things which we can directly see. If we study plants or electricity, those are things which we can see but sometimes there are things like gravity which we can't directly observe but we can still observe what they do.*
>
> *2: Yes miss I have an example of this. If we give plants water for example, we don't see them drink but we know that they do because if we don't give them anything they die.*

6: Even forces, we don't see them but we know that they are there because if I push something it moves back

9: We observe the behaviour

(School B focus group 2)

The excerpt above illustrates children's ideas on what they consider appropriate to be classified as scientific observation. Children accounted for anything which can be perceived by the senses as observation. They identified different ways of observation, including tools to heighten or strengthen the senses such as microscopes.

4: Sometimes we have to keep on trying or else find another way

I: To observing?

4: Yes

I: Ok…like what?

4: Like um using special equipment

1: Like microscopes

2: Sometimes it's hard to study these things because we can't see them but we know they are there because people developed things like microscopes so that we can be able to see some things which we weren't able to see before

(School A Focus group 2)

This excerpt illustrates how children reflected on how observation and the equipment used to make observation possible. Some participants took observation to mean acquisition of knowledge from a primary sense; heavily dependent on sense experience. This view of scientific observation can be likened to an empiricist view of science where observation is founded on the involvement and perception of sense experience. Such discussions resulted in children inquiring into how some phenomena are difficult to observe when the senses are limited. This idea prompted children to then discuss the use of scientific instruments to aid or enhance sense experience; such as microscopes and telescopes. Children explained that with technology scientists can create the means for observation and use these means to aid in direct observation of scientific phenomena; such as in the case of 'microscopes'.

Further to children's talk on different ways of observing, other ideas were provided including studying physical objects, studying non-physical objects such as gravity, and as a means for testing what cannot be directly tested using experimental methods.

> *2: Even if we don't experiment and just observe things it is still science*
>
> *6: But then it's not science if it can't be tested*
>
> *1: Yes it is… because you can still test it by observing*
>
> *3: I agree because sometimes when scientists study the planets or the sun they can't always experiment on them so they just observe them from a distance*
>
> *6: But you have to test the ideas for them to be scientific, you need to see if something is true or not*
>
> *2: yes but not always*
>
> *3: sometimes yes and sometimes no, sometimes they have to just rely on observation because there is nothing else they can do*

(School A focus group 1)

Further into the dialogue, children generated more thought on the criteria on which scientific observation is characterised. While children seem to classify science as being empirical, there was some disagreement amongst children on whether observation alone can justify scientific knowledge. From the excerpt, children seem to have the idea that scientific observation is testable and correctable. They argued that observation is rationalised with experimental work to make it empirical. This idea was strengthened further by the following comment from another focus group.

1: We test ideas based on what we have observed. Yes ideas come from observation so they need to be tested

3: Not always

5: almost always because what we observe is just an idea. You have to prove it.

3: how?

5: by studying it…experimenting to see if it's correct

(School A focus group B)

Children's contrasting views of observation were clarified when discussing scientists' role and disposition when it comes to science, and the process of observation. The argument from the excerpt above developed into discussion on what guides scientific observation and how scientific ideas develop from observation. Based on the excerpts illustrated above, children demonstrate the idea that science is a process which starts with observation. One questioning criteria of observation that has perturbed children to arrive to the view that scientific observation alone might not be empirical, is a result of the theory-laden nature of scientific observation.

5: we have to think about what we are observing or else we won't always see things

4: like what?

5: like if you are studying about stars and planets and you look out into the sky, you know what they are because we did them at school

2: yes or else we wouldn't know what they are…sometimes observation can be wrong…

I: wrong how?

2: because what we observe can be totally different to what it actually is. It depends how much you know

School B focus group 1

The theory-laden nature of observation is one core idea that has been identified in this social representation. Children's ideas on scientific observation highlights that there is understanding of scientific observation as a human activity which is therefore subjective by nature. They regarded that observation might be influenced by other factors such as prior knowledge. Children acknowledged that scientists' prior knowledge and experiences affects the way they as scientists sees the world. The next excerpt shows how these participants constructed their assumption based on the scientific paradigm card (card 4) during the discussion.

> *2: we can have different ideas about the same thing… we have been taught by different teachers, perhaps read different books and we all live different lives*
>
> *1: we see things from our point of view. I can see something, and other people see something else*
>
> *School A focus group 1*

Prior knowledge and experience were discussed amongst children as being factors which enable scientists to observe the world around them. Children's talk identified a link between the act of seeing with one's own eyes and the mind's way of observing by sourcing into prior knowledge, past experiences and reasoning. Children evaluated how our prior knowledge affects the way people study things.

> *3: Sometimes we don't understand other people because they have a different experience to us*
>
> *5: Not always sometimes we observe the same thing (…) other times we observe something else, something that not everybody can understand and different people will have different ideas about it. Like for example we have different ideas about books.*
>
> *School B focus group 3*

Reflections on prior knowledge encouraged children to discuss how experience is one influencing factor which permits one person to observe things differently from others. This recognition of diversity in observation does away with the pitfalls of human sense, in that diversity in knowledge, experiences and ideas, results in the unity of ideas. Further to this point, children acknowledged

> *6: In science we don't just do experiments sometimes it can also mean thinking about what has been done already and trying to figure stuff out*
>
> *School A focus group 1*

Another focus group highlighted the same common understanding among participants engaged in the discussion; that a scientist's background is a crucial factor when it comes to rationality in the act of observing something. Having objectified scientific observation in their earlier discussions, the following excerpt demonstrates how these participants anchored their ideas on observation to contend with how scientific observation can be affected by the scientists' level of education and experience.

> *3: a scientist who has been doing what he's doing for a very long time…had time to think about it*
>
> *7: scientists… they have lots of experience and other people wouldn't be sure because they haven't been studying it*
>
> *8: Scientists…know more about the world because it's their job to study it, other people wouldn't be able to study things because they wouldn't have done them*
>
> *5: How we study things…we learn from what others have done (…) learn from their mistakes, they see what they have done before and arrange that*
>
> *School A focus group 2*

The reasoning behind observation has also been commented on, with the acknowledgment that there is a scientific way of thinking due to the scientists' prior knowledge and ways of working with other scientists. Focus group discussions explored other ways of knowing besides observation, such as prior knowledge and experimentation, with children's talk suggesting that observation leads scientists to infer what cannot be directly observed.

1: We have to think about what we are observing because it's not just seeing things

I: Then what is it?

1: I don't know…they think about something maybe and then they understand what's happening because they make sense of what they are observing

4: mmm… they may guess how things are because they thought hard about them

(School B Focus group 2)

A logical connection lies between scientific ideas and scientific observation, in that scientific ideas direct what can be observed. This representation of science suggests a Platonic view of science on the notion that observation through sense experience is not only attained through the physical world and that communication and rationalisation have an important part to play in the way we 'observe' the physical world. However, similar to a positivistic view of science, children report that observation directs experimentation in that there is a clear link between discovery made through observation and experimentation to test whether what has been observed (scientific ideas) are true or false. However in contrary to a positivistic view this outlook of science does not suggest a formalistic view of science (where observation leads to ideas) , on the contrary, the positivist view of science discussed in dialogue is one which is taken in the context of inquiry, i.e. that ideas lead to experimentation. This dichotomy is expressed in the excerpt below.

1: But we can see almost everything in science because they sort of want to give evidence

2: Yes but they can still give evidence of gravity

I: From where do they get the evidence?

2: I don't know what evidence they give

3: They explain what they think happens

5: Maybe they did an experiment because after we observe something we usually experiment so see why it happened

I: Ok so where do you think scientists get their knowledge from?

4: They make theories and then they experiment their theories

(School B focus group 2)

This excerpt clearly identifies the challenges of observation, leading to these participants evaluating how unobservable phenomena such as air or force can be studied. It is interesting to see that these participants have used their idea of observation as sense experience to state that observation can also imply observable effects such as identifying the presence of something through other means such as feeling the force. It is also interesting that participants mention theories here, and how scientists develop theories to explain phenomena. Moreover, the last statement identifies a clear link between developing theories (or in other focus groups, ideas), and testing these theories to identify which ones are correct and which are not. The next representation shall discuss this in more detail.

6.2 Science relies on experimentation to differentiate between what ideas are correct and which ideas are not

As evident from the previous social representation, children commented on the empirical nature of science, suggesting that science needs to test scientific ideas in order to find if they are correct. In this social representation talk centred specifically on scientific methods. Children elaborated on the link between observation and experimentation. The relationship between the two according to children, lies directly in the nature of participants' ideas about science being contestable and subject to testing. This argument was brought about by the discussions on cards 2 (scientific method: a step-by-step guide to do science) and 3 (falsification: disproving theories through evidence). Further to what has been discussed on observation as a scientific method of inquiry, children discussed how scientific observation and experience are subjected to testing (a way by which predictions are tested to determine truth).

Further to what has been articulated in the first social representation that scientific observation is subjective, children here elaborated on their views by claiming that due to the subjective perception in scientific observation scientific ideas need to be tested. Like Bacon's ideas about scientific observation, participants believe that observation (which is a human activity) is limited and thus subject to errors of perception, which can affect the way science is studied. As a result, the below excerpt illustrates that ideas need to be measurable to test whether they are correct or not. Such ideas can only come from experiencing the phenomena.

> *2: Before we do an experiment we observe it first and think about what the result may be*
>
> *3: Sometimes we have a theory before and we experiment to see if it is true*
>
> *6: I think science they get it from observing what they do at home, sometimes they see things happening in the world and they want to test it out.*
>
> *(School C focus group 1)*

In the above excerpt it is worth mentioning that participants' thought processes follow the logical progression of the same method displayed on the cards; that scientific work starts with observation and then the hypothesis gathered from the observation is subjected to testing. However, five focus groups argued that there is no particular method which needs to be followed in order to do science. One participant stated, "Yeah exploring and discovering is still science and there is no method for that". Other participants in the group agreed with the statement, with participants claiming that science is all about exploring and discovering new things and that science does not always come with intention. This illustrates that children have recognised the two types of processes in science; inductivism (starting from observation to form ideas and draw conclusions) and deductivism (exploring ideas to draw conclusions to form a theory).

The process of induction in science was discussed in the form of an inquiry into how science makes a distinction between what is true and what is not. As seen in the comments below, children argue that experimentation makes a distinction between the ideas which are correct and the ideas which are not. However, dialogue also shows that a correct or incorrect answer can potentially enquire into more ideas which would need to be tested again.

> *5: We have to explain why something is wrong, we can't just have an opinion, science doesn't work like that. We have to test it further*
>
> *I: Can scientists ever be wrong?*
>
> *5: Yes but they show what they did wrong because they have to show proof whether it worked or not…I don't think that science focuses on what doesn't work, it will take too long to do that. I think that science tries to understand what works and how it works instead*
>
> *6: Because you might get it wrong and then you have to repeat and see if it's correct you have to repeat over and over, because you never know if it's going to be correct or incorrect.*
>
> *(School B focus group 3)*

While inductivism seems to be the most common process of science amongst children, children acknowledged that there is no process which is superior to the other. However, one participant stated *"We can't just go about doing what we like in science because it's work and scientists have limited time to do their work".* The comment presented here suggests that while children recognise the creative and innovative aspect of science, they also appreciate that science has to satisfy requirements beyond scientists' own interests and observations. As a result, the linear view of science depicted in Bao Bao the panda's view of science, encouraged children to make the distinction between the processes of doing science, versus the presentation of the processes of science that is communicated to the public. They argued that the Bao Bao's linear view is the way that scientists present the method and results to other scientists and to the public. Pointing out that the scientific method it's the way science is presented to be easily reproduced.

> *1: they are exploring not learning so they don't know what is going to happen in the experiment. They might have to do it all over again so the second time will not be the same.*
>
> *6: We don't have to follow methods in science but sometimes we have to- to learn*
>
> *4: At school we have to follow a method most of the time because we are learning how to do it*
>
> *(School B focus group 1)*

It is evident from the excerpt above that one child's distinction between exploring and learning is precipitated by conception that what is done in school science is not what is actually carried out in real science. Furthermore, children do not seem to find exploration as a means of learning. There is also an underlying conception that scientists are not learning anything new just by exploring.

Contending with the concept that some scientific ideas are created through the process of discovery and others are developed specifically due to the needs of society. Children noted that there are no specific requirements to do science, however they expressed understanding of having a method to help scientists reproduce experiments and achieve transparency. Children argued that 'other people' need to know how scientific knowledge has been derived.

> *1: We have to have rules because we can't just get information from things that we see and say that they are true, we have to understand what other people think about it, what other experiments have been done and then experiment*
>
> *(School A focus group 2)*

Children believed that scientific methods as they have come to know about them in school science are a product of discovery, a set of guidelines which help them 'as learners' to replicate what scientists have done to achieve the same results. This idea of scientific method being a straightforward process which helps other people understand and replicate their study- recognises children's own experiences of science as being something which is taught and replicated as in the case of science education.

> *2: if we don't have a rule or method than we wouldn't be able to understand how people did it before…we need to be able to understand where it came from*
>
> *1: We have to have rules because we can't just get information from things that we see and say that they are true, we have to understand what other people think about it…*
>
> *2: If people didn't observe rules everybody will do as they wish and then it would be difficult to understand it and see what's true and what's not*
>
> *8: I think that scientists have to follow a certain path to an experiment because then it won't be accurate*
>
> *(School A focus group 1)*

Children did not elaborate on what makes experimentation a means of testing superior to other forms of testing. However, children commented on the principles applied to experimentation; in that experimentation demands either the revelation that the scientific idea is true or that there is lack of knowledge in its claim for truth. This was a very common understanding between participants from different focus groups. It is also worth noting that children demarcate science from other ways of knowing due to its validation through experimentation- testing of ideas.

Children's understanding suggests that they recognise a problem with induction, especially in relation to how scientific ideas (which are subjective) require more rigorous application (testing through experimentation) which for children is seen as standards by ensure that knowledge is correct in light of the evidence supplied through rigorous standards. However, participants did not see falsifiability as a key feature of scientific practice. Having said that, a lot of value was also seen to be placed on how such standardised scientific methods (such as experimentation) offer measured answers, ensuring quality standards when it comes to the development of scientific knowledge. This sort of common understanding amongst children is noted in the next section, which discusses participants' objectification of scientific ideas and how these are anchored to fit in the realm of doing science and producing scientific knowledge.

6.3 Science is a process of building ideas with evidence and fitting these ideas together in a way which makes sense

Participants described how scientific work is verified and co-constructed and collated in a way which systematises into a body of knowledge. The illustration on the 'Scientific Paradigms' card, with the scientists looking at a large elephant and only seeing what is in front of them, prompted children to associate science with the large elephant. Through the metaphorical use of science as an elephant-sized puzzle, participants focused on how scientists might only study just a small part of science. This association encouraged participants to formulate ideas about how scientists work together to be able to see the bigger picture. Participants discussed how scientists observe through sensory means and formulate ideas based on their observations, as a result, in their focus group discussions, participants elaborated on the need for scientists to work together to share their ideas, in order to get representative knowledge which is more accurate. The following excerpt illustrates participants' negotiations of their ideas with reference to scientists'.

> *5: Yes because to understand something we need to listen to everybody because they… then , I mean we can fit everything together like what we were saying before when we said that science is like a puzzle*
>
> *3: Most of the things in science are related to one another…they build on each other so every idea is important*
>
> *7: I think all ideas are important because if two people are working together they can come up with better ideas*

6: I think if lots of people work together they can help each other work better and come up with new ideas, sometimes even faster too

1: Scientists themselves can't judge which idea is important because they are all scientists so every idea is important, I think they fit all their ideas together so that they make new discoveries

5: I think that there is truth in science because they do it lots of times and different people, I mean different scientists do it too to make sure they are right

(School B focus group 2)

In the excerpt we can see how children objectified science to be a structure of several ideas that unify to gather a general understanding. Here participants speak about the interrelatedness of ideas and how together these produce a clearer understanding of how the world functions. Participants used the puzzle metaphor for science to mean how scientific ideas are pieced together when scientists work in groups to achieve something which is biggerby fitting all scientific ideas together.

In this respect, these associations of science produced through the puzzle metaphor, have connections to participants' earlier assumptions on the construction of knowledge and how science discovers answers about the physical world through observation and experimentation. In the following excerpt participants elaborate on the nature of ideas and how ideas can either fit with other scientists' ideas or they might not. When asked about what happens if ideas do not fit together, children argued that some ideas would be wrong but might be helpful in the future so they are still important.

5: Ideas are all important until we test them to see if they are correct or not

8: I agree… they don't know if something they will try fits or not, it might work or it doesn't

6: I think they are all important so that we can share them with each. If they share their ideas than they can investigate and learn more

(School A focus group 2)

Participants regarded how having several scientists (true to the picture), studying one particular aspect is more reliable than having one scientist studying a particular area. This connects to discussions on how scientists come with their own prior conceptions, and ideas and the need to eradicate bias when testing. The main idea discussed was how the sharing of ideas can bring forth a better understanding of observation and a reliable form of testing. The next excerpt demonstrates children's thought processes on the concept of generating ideas and testing these ideas in light of new evidence.

5: Yeah but sometimes a new one comes a lot which is better, it happens all the time

8: Yeah like with technology and stuff

6: Maybe the first experiment was right and the other one was right from the first

5: For example, one of the experiments was more successful

6: Yeah

5: Yeah that's why we test things all the time, if something is more successful then obviously it's better and we use that one.

6: It all depends if it works for that particular time, an old idea might be useful another time

5: When?

6: When things change

5: I am not understanding

6: If we have an idea now and it works with the other ideas that we have then it's perfect but if one of these ideas is wrong then all the ideas will also be wrong

5: Then everything will be wrong

6: Exactly and then if somebody thought really differently then he might be the one who is right and his idea will be better.

2: Yeah or else if they share with others what they have found they will be able to see learn more and will be able to make better sense of it, for example they would realise that it is an elephant

(School B focus group 3)

The excerpt illustrates how participants reached an understanding of how ideas work in relation to other ideas. One participant argued that some ideas are more successful than others, which opened a discussion on how less successful ideas might still be as useful. On this statement, participants elaborated on how ideas are time and context dependent. Arguing that what was once a good idea might not be as successful in the future when new ideas come along. This argument then led participants to discuss how ideas change and what happens when just one idea changes. One participant was concerned that if one idea is wrong and happens to change, then the other ideas might change too as a result.

Furthermore, participants considered that ideas might change in light of new evidence, “sometimes things which have been true in the past are not true anymore”. It was also acknowledged that some aspects of scientific knowledge are more challenging and might not be subject to change. The following excerpt demonstrates this complexity by participants’ argument that ‘facts’ are difficult to change.

6: There are some things which can never be changed

4: Like what? … everything can be changed

6: No not everything… like for example that we need food, air and water

4: Exactly like some facts Miss

(School C focus group 1)

It is vital to note here the distinction made between facts and ideas and how these appear in talk about science. The next section shall illustrate how induction can cause a limitation when certain statements could not be justified with science.

6.4. Science has its limits

The participants' argument that some ideas are more tentative than others led focus groups to discuss the reliability of science. As previously discussed, participants engaged in discussion of how reliability comes through an exchange of ideas amongst scientists and after removing potential bias through testing. Talk on reliability and the tentativeness of science encouraged participants to negotiate between themselves some examples of this, for example how science is limited to studying only the physical world through sensory experience. The unpredictability of science as a result of its dependency on the social aspect and the context of time and space was underscored by participants as the following excerpt illustrates.

1: I think that it can't really study the mind

I: Why not?

2: They still do tests on the human brains

1: Yes but there are still some big question marks about it, they can't really understand what is going through a person's mind in terms of thoughts and things like that

2: Mmm, true and even studying afterlife is difficult with science

4: Anything which is not really tangible is difficult to study in science I think

2: Mhm morals and things like that

3: They try to come up with their own ideas of what happens after we die, or where we come from and things like that but these are just ideas not facts

(School B focus group 2)

3: Hemm suġġetti oħra barra science li jistudjaw ċertu affarijiet 9: Mars u l-pjaneti l-oħra 8: Ehe sistema solari oħra li mhijiex fis-sistema tagħna I: Għaliex ma nistawx niskopruhom dawn? 9: Għax ma nistawx nagħmlu esperimenti fuqhom 8: Ma nistawx immorru f'dawn il-postijiet 6: Ehe ma nistawx immorru fiżikament fuqhom, sakemm ma joħolqux xi ħaġa, xi apparat biex nagħmlu dan 1: Għandna informazzjoni fuqhom għax ikunu studjawhom b'xi mod imma ma nistawx inkunu ċerti fuqhom 5: Eżatt forsi hawn pjaneti li qegħdin il-bogħod u ma nafux bihom 3: Jew hemm il-ħajja fuq pjaneti oħra u aħna ma nafux	3: There are other subjects besides science that study some things 9: Mars and other planets 8: Yes, other solar systems which are not in our solar system I: Why can't science study these? 9: because we can't experiment with them 8: we cannot go to these places either 6: yes, we can't go there physically, unless they create like an equipment to do this 1: they have information about them but they can't be sure about it 5: exactly, maybe there are other planets far away that we don't know about 3: or perhaps there is life on other planets and we don't know yet

(School C focus group 1)

In this excerpt, it is noteworthy to acknowledge the way participants demarcate science from other ways of knowing. It is interesting to acknowledge which subjects children think are characteristic of science and which are not. For example, from the excerpt it seems that children do not recognise neuroscience and theoretical physics.

The other point is that participants find it challenging to articulate how scientists could ever study something which is sensory inhibited. For example, the mind (see also the following excerpt). This links well with previous representations of how science is based on the sensory experience of the scientist, which is very much rooted in empirical approaches. As the excerpt illustrates, there is a clear distinction between ideas and facts. The boundary between the two lies in the lack of physical testing when it comes to ideas. Further to what has been discussed in previous representations, this understanding is linked to how children identify science as being measured with either true or false answers. This is because participants brought up the idea of morals and how science cannot effectively study morals due to their subjective nature, i.e the concept of no right or wrong. This concept is explicitly referred to in the following excerpt.

1: I think that science can't study why people do things because they can't get inside our minds

9: In science things have to be either wrong or right

2: Not always…

9: Yes all the time… like when we do experiments… it either works or it doesn't

3: Sometimes yes but not always because if… when they do experiments they can still have an opinion of the results they are going to get

2: Yes how they do an experiment can also affect what results they get

5: I agree

(School B focus group 1)

This excerpt looks at the exchange of reasoning between participants and how they arrived at the common understanding that while science is measured by whether something gives is either true or not (i.e whether something gives a positive or negative result when ideas are tested), participants arrived at the assumption that scientific findings are still subjective as a result of prior expectations and the background of the scientists, especially so, since 'experimentation' is still a human activity. Participants' negotiations about the limitations of science extended to different types of knowledge systems which permit the study of the metaphysical. The excerpt below illustrates the discussion that takes place on creation and the distinction between what has been created by science and the origin of species.

3: It [science]can’t change weather

1: I think science can create plants no?

4: No

2: But they create the seeds

4: No seeds come from the plant

2: but scientists can make plants

4: God created plants and then they make seeds and the seeds make plants

2: Like the life cycle

4: Yes

1: God created everything which science can’t do

2: Yes

4: There are somethings which we can’t explain because God created them

(School B focus group 3)

While participants acknowledged that science is also a product of discovery, i.e. scientific products, negotiations of what science can and cannot do, resulted in participants agreeing that there are some things which science cannot possibly create due to its limitations in sense experience such as changing the weather and that there is synthetic life. Metaphysical knowledge is seen to be disassociated to science. The concept of the creation of life is seen as something which is beyond scientific capabilities. Here we can also see an exchange between science and religion. The concept that religion takes over what science cannot study is also critical in forming their associations about the reliability of science which shall be discussed in the next section. This brings the next representation that solidifies children’s social representations.

6.5. Limitations to science leads to other ways of knowing

Subsequent to participants’ discussions on the limitations of science, and the methods utilised in science to construct knowledge, participants’ argued that ‘other ways of knowing’ can help fill in what cannot be studied in science. The reliability and validity of science were discussed during various points of discussions throughout all focus groups. The methods utilised in science; observation and experimentation were both considered as reliable (through evidence) and valid in the sense of being limited to study only the physical world.

> *5: We have to explain why something is wrong, we can't just have an opinion, science doesn't work like that. We have to test it further*
>
> *2: We believe what scientists have said*
>
> *I: Why?*
>
> *2: Because scientists have tested it out*
>
> *8: Other people could have just said what they thought*
>
> *7: Other people could have read about it too, like teachers, they read about it and then they teach it to us*
>
> *5: Yeah but scientists they read what other people have said and then they test it out to see if it's true, if it's not we don't believe it*
>
> *I: Can scientists ever be wrong?*
>
> *5: Yes but they show what they did wrong because they have show proof whether it worked or not*
>
> *4: They have to experiment and check*
>
> *(School A focus group 2)*

While this excerpt shows participants arguing on experimentation, reliability is also a very important concept which is considered here. As seen from the data, reliability in science is achieved through evidence and peer-reviewing (i.e. showing proof and rechecking), here reliability is also discussed in terms of a characteristic of science which demarcates it from other ways of knowing. The excerpt supports children's views of science as a reliable source of way of knowing.

There were some common constructed ideas amongst groups that characterise science as just another way of knowing amongst others. The subsequent excerpt is a discussion that tookplace in one focus group where participants, (through a process of objectification andanchoring), managed to anchor scientific limitations to medicine and its recent challenges with the pandemic and vaccines. It is crucial to note that this particular focus group anchoredmuch of their understanding of science through examples relevant to the medical use of science.

9: …forsi l-antika ddum tofiodha imma gfiandha togfioma tajba imma ddum iżjed biex tfiq u l-ofira, l-ġdida tfiq iżjed malajr imma togfioma fiażina, ma jfissirx li l-ofira mhux tajba. Biex rawha tajba gfial dak iż-żmien sinjal li tafidem, kieku ma vvintawix 3: Jien nafiseb kull idea togfiod ta', gfiax kull idea ġiet minn xi fisieb 2: Imbagfiad dejjem skont jekk l-idea ma tibqax togfiod gfiax meta jgfiaddi ż-żmien nużaw teknoloġija li tgfiina biex nofiolqu u nafisbu b'mod differenti allura ta' qabel ma narawhomx tajbin iżjed 3: Imma kienu tajbin gfial dak iż-żmien 2: Ehe dik ukoll 3: Eżatt	9: maybe the old one tastes better but it takes longer to treat and the new one has bitter taste but treats us quickly…it doesn't mean that the other one is not good. If it was good in the past then it means that it's still good, eitherwise they wouldn't have invented it 3: I think that every idea counts because each idea has developed thought 2: It depends if the idea still counts because as time passes we use technology which helps us create and think about different methods so we don't see old ones as useful anymore 3: yes but they were good for that time 2: yes that too 3: exactly

5: Jien nafiseb li ġieli iva u ġieli le, gfiax eżempju l-influwenza kienu jiefiduha f' darba imma tal-covid trid toqgfiod tofiodha darbtejn, jiġiefieri mhux dejjem imorru gfial afijar	5: I think that sometimes yes and sometimes no, because for example they take the flu once but with Covid you need to take it twice, so we it's not always for the better
5: …hawn minn jfiq mhux bil-mediċina ukoll	5: There are people who get treated without medicine too
1: Jiġifieri kieku kelli ngfiid eżempju n-nanna tagfimillek tafilita b' affarijiet mill-kċina biex tfiq u t-tabib itik mediċina, ta' minn se tuża, l-mediċina tan-nanna jew tax-xjentist?	1: so if I had to give you the example of your gran making a mixture from things she can use in the kitchen for you to get better and one which the doctor prescribes for you, what would you choose your gran's or the scientist's?
4: Skont kemm inti sick, jekk ma tkunx sick, jkollok xi fiaġa żgfiira fiafna niefiu tan-nanna imma jekk tkun sick fiafna u ddum fiafna b'xi marda imbagfiad indur gfial dak li fiolqu x-xjentisti.	4: Depends how sick I am, if you're a little sick I would take my gran's medicine but if you're too sick or take too long to get better I would resort to what the scientists have created
3: Imma tat-tabib tagfimel il-fisara ukoll	3: but the doctor's can harm you too
2: Gfialhekk tiefiu dak li fiolqu s-scientists jekk tkun gravi biss…Jien ma nafisibx li s-science jagfimel kollox tajjeb	2: that's why I would take the scientist one if it's worse…I don't think that everything science does is good
5: Nafiseb hemm fiafna affarijiet li jafu jkunu tajbin, xi mdaqqiet in-nies immorru l-ewwel gfias-science gfiax hemm l-evidenza	5: I think there are some things which might turn up to be good, some people resort to science immediately because there is sufficient evidence but it can cause harm too

li huwa effettiv imma xi mdaqqiet jagħmel il-ħsara ukoll	
3: Eżatt ħafna mediċini jagħmlu l-ħsara	3: Exactly lots of medicines cause harm
2: Ma tkunx taf eżatt x'qed tieħu	2: You wouldn't know what you're taking
I: U tan-nanna aħjar għax tkun taf x'qed tieħu?	I: So gran's would be better because you know what you're taking?
2: Ehe	2: yes

(School C focus group 1)

There seems to be a set of criteria in children's discussions that demarcates science from other ways of knowing. As discussed in the first representation (refer to 7.2), science is seen by children as physically limited to studying phenomena through sensory perception. What is not based on evidence (i.e. not tested), cannot be considered scientific. This is where other ways of knowing come in to explain phenomena which science cannot yet study due to its limits. In the above excerpt we see an exchange of ideas about how science is objectified to an example within the medical field of science, a more common occurrence of science in children's daily life. Trust in science or lack thereof is one concept which is revealed in this social representation. The stigma of pharmaceuticals as being harmful has its effect here as participants are concerned over their lack of understanding and knowledge when it comes to medicine. Moreover, this excerpt brings to the forefront two types of knowledge, one which is perhaps based on experience (such as gran's treatment) and one which is based on sufficient evidence (scientific treatment). The argument is not to say that scientific knowledge is not reliable but rather hints into the concern that the scientific process is not something which children experience and therefore cannot particularly assimilate its principles and reliability to its full extent.

6.6. School science as a developed body of knowledge intended for the learning process

In response to school science, children argued that there is quite a gap between the science done at school and real science, in terms of purpose, structure and product of doing science. Children identified that the purpose of school science is to understand and re-create what scientists have already done in order to learn science. They mention that the aim of school science is not to discover but to learn scientific knowledge, whereby they explained that due to lack of expertise, the aim of school science is not to communicate their findings with other people, as scientists do.

> *7: we are not professionals, we don't share our experiments with other people like scientists do*
>
> *4:at school we do science, like experiments and stuff which is not extraordinary*
>
> *3: Yes like we do science which has already been done before. Sort of um, you know how like science discovers things…?*
>
> *I: yes*
>
> *3: well the science that we do at school is not like that, we don't invent new stuff.*
>
> *School A focus group 1*

It was a common held belief amongst children that "at school we learn and scientists on the other hand discover" (School A focus group 2), with children suggesting that "actual science discovers new things all the time". It is interesting to note from the excerpt below that children reasoned that the difference in aims between real science and the science done at school influences the way science is communicated.

> *8: we study what other scientists have done*
>
> *3: scientists explain what they think happens*
>
> *5: they experiment because after they observe something or study something they test it*
>
> *4: yeah they come up with theories and then they experiment their theories*
>
> *I: how is that different to what you do at school?*
>
> *4: we don't actually discover, we're still learning*

3: we learn from what they have done

(School C focus group 1)

Furthermore, children argued that experiments done at school are not considered real as they do not aim to discover.

1: scientists do all sorts of experiments.

2: yeah it's not the same

I: what do you mean?

2: scientists do science and we learn it

School B focus group 2

Children from other groups also pointed out the differences in the purpose of experiments and how the aims of science influence the process of science.

7: we discover things but it's not the same

I: why is it not the same?

7: we are not professionals… we study what is already there

1: scientists they do more experiments and they share them

2: yes they experiment more than we do as they have to come up with the experiment

I: how is that different to what you do?

2: they do different experiments to discover, not like us, we don't discover

(School B focus group 1)

2: We do experiments to learn not to discover things, scientists do that. We just get to understand what scientists did before so we don't have to keep testing, because we know that it is already true.

(School A focus group 1)

It is clear from the excerpts that children understand that there is a difference in the aims and methods between science and the science done at school. This shows that children feel that what they do in school science is not reflective of how actual science is. Perhaps there might be a gap in the way science is portrayed in society and the way science is done at school.

6.7. Conclusion

In conclusion, this chapter examined children's social representations of the nature of science and how these social representations were acknowledged in philosophical dialogue. Participants made this possible by using examples from their everyday interactions with science and sharing their ideas with other focus group participants. The network of social representations emerging from the dialogue offers a consolidated understanding of what science is, its characteristics, limitations and how it works in a society. The social representations uncovered children's hidden assumptions that 1). Sense experience is influenced by prior knowledge, 2). Science relies on experimentation to differentiate between which ideas are correct and which are not, 3). Science is a process of building ideas with evidence and fitting these ideas together in a way which makes sense, 4). Science has its own limits, 5). Limits to science lead to other ways of knowing.

The examples frequently used by participants served the function of objectifying science as a discipline with which knowledge is generated about the physical world through the senses. This same representation shows consistency with the representation that science has its limitations. According to children, the limitations lie in science being limited to studying the physical world through the senses. This characteristic of science determines what science can and cannot do i.e. processes of science which is another representation emerging from dialogue. Through this social representation, there is the understanding that science is based on experimentation which demands exact measurement of whether ideas are correct or not. By consequence of how science studies the world (through physical stimuli) and its quantitative measurement of the world results in science having its own limitations as to what it can study and what science can have an 'opinion' on. So much so that the social representations discussed here suggest that what is regarded as scientific is open to discussion when it provides scientific insight into something which is meta-physical. Its characteristics, such as rigorous testing and validity coming from multiple ideas, ensures that evidence is sufficient and trustworthy.

Chapter 7

Teachers' social representation of NoS

7.1 Introduction

Teachers' social representations were gathered from both focus groups and interviews; two interviews with teacher participants and three focus groups with teacher participants. The research techniques used played an important part in the kind of data collected from the interview and focus groups. As previously mentioned in Chapter 5 and 6 on methods, one limitation of using focus groups was that the dialogue was limited to only two individuals; the interviewer and the interviewee, resulting in a lack of exchange of ideas, elaboration and argumentation. This limitation can be seen to the extent of the depth in the network of social representations extracted from teachers' dialogue.

Each social representation will be discussed in detail noting on how each representation was communicated in dialogue. Each social representation will be followed by a separate section which discusses how the concepts within social representation are addressed in the philosophy of science. This chapter shall thus address the following questions: What are the teachers' social representations on nature of science?

Talk amongst teachers centred on scientific methods; how science enquires about the physical world and how scientific work is experimental. All teachers in both focus groups and interviews discussed how methods used in science differentiate, or on the other hand are similar to the methods used in school science. Participants elaborated that lab work, hands-on approaches and experiments are the first things that comes to their mind when they think of science. Other participants also acknowledged that science is based on enquiry about the physical world, with assumptions that science aims at solving problems in the physical word. This will be discussed further in social representation 7.2. below.

In contrast to children's discussions, teachers did not use examples extensively to contextualise their ideas. However, there were some instances in several discussions were examples were drawn from applied science such as the use of science in medicine. Talk centred on vaccines and science's role in solving problems within society and creating means for research in medicine, society and beyond.

Five social representations were identified from teachers' focus groups and interviews. The next section will explore these social representations in detail and identify how these social representations address questions and concepts within the philosophy of science.

Social Representations
Science follows the demands of society
Scientific evidence derives from both observation and experimentation
Science is a process of fitting previous ideas together with new ideas
Science strives to be objective; truth, whether scientific or otherwise remains subjective
School science reflects general science

Table 7.1. Teachers' social representations

7.2. Science follows the demands of society

In all focus groups, the importance of science was discussed amongst all teachers in terms of the role it plays in society. Teachers discussed the need for science to be purposeful to contribute to the needs of society. Participants pulled examples from current socio-scientific issues such as vaccines and the role of science in pharmaceuticals and medicine to discuss the significance that science has on the creation of new knowledge and scientific products. The value of science was also discussed in terms of its necessity to satisfy our basic needs such as finding cures, improving living standards and in the creation of products that impact or improves our lives. To a lesser extent, the value of science was also discussed in its impact on information technology and the influence that this had on the world. The excerpts below are taken from different focus groups and interviews with teachers but each one highlights the role and value of science within society.

Science is development…a process…always developing new things…always accountable for a creation, so something that builds on one to another… always discovering new things and helping in developing aspects of life

(School A teacher focus group)

1: Science is influenced by what is happening around us and so they base their ideas on that, I think.

3: Yes, I think that scientists discover things according to the needs of society

2: I think it's highly purposeful, they do everything according to the demands of society…I mean…these people don't do it just for fun, it's their line of work so of course they are paid to discover things…but…I don't really know…I do think that there are some demands that they have to follow like in the case of vaccines and stuff like that

(Mixed teacher focus group 1)

Science is everything around us… everything we have around us is created through science somehow… breathing, driving, eating…science is very relevant to our daily lives, more so with technology today. With technology scientists are able to create and discover many things, it has become essential… So science…it's extremely important…

(School B teacher interview)

The excerpts above articulate on the value of science in society and how science satisfies those needs. Science was often discussed as a process here. A process of solving the problems which arise from within the environment. Participants spoke of demands by drawing in on current issues with the production of vaccines to meet the demand of the public. It is interesting to note that participants draw on the 'problem-solving' side of science to define its role and purpose as a discipline. This is not surprising as in all focus groups and interviews participants expressed the lack of confidence they have in their ability to understand the process of science, and the limited knowledge there is out there for the public to truly engage with the work done in science.

It was also noted from the last excerpt the role of technology to satisfy the needs of society and the value it has in terms of scientific discovery. This concept could ideally have been expanded to include more detail such as by drawing from examples to discuss the role that technology plays in science. The concept of technology in science was not a concept which was directly identified from philosophy of science, however it could have been equally valuable to shed light on the perceptions that participants have on the concept of technology and science.

In the next excerpt participants discuss once again the role of science in society and the kind of relationship science has with society and the more specifically the environment. Teachers talked briefly on scientists being able to discover patterns in the environment to inform scientific knowledge. Although this concept was not elaborated on in the interview, the participant expressed how scientific knowledge changes as a result of changes within the environment. This idea further strengthens the concept of how science is informed by the needs of society.

> *Science discovers and studies things which exist amongst us at that time…there has to be purpose why they are finding things at that certain time…science is built on purpose…everything is tied to things which are happening around us…there is truth to what we can study but things change through the years. Scientists can only discover patterns in the environment, that's why scientists cannot exactly predict what can happen in the future…like the flu vaccines…they are predictions of the viruses that can come out the following year.*
>
> (School B teacher interview)

> *2: I don't think that science is that entrepreneurial to be honest, I think that it is highly purposeful but they do everything according to the demands of society…I mean these people don't do it just for fun, it's their line of work so of course they would need to get paid, to discover things yes but also to discover things like, like I don't really know…*

but I do think that there are some demands that they have to follow, as you said the vaccine and things like that

(Mixed teachers' focus group 2)

In addition to the relationship between science and society, the first excerpt above provides some insight into the concept of predictions within society as a result of the role of science to discover patterns within the environment. Here, examples were once again drawn from current socio-scientific issues such as flu vaccines and viruses to illustrate how science makes predictions based on prior knowledge. This hints into other social representations of how prior knowledge might inform new knowledge and discovery.

Corresponding to this excerpt, the following excerpt extends to provide examples of how socio-scientific issues influences truth and scientific knowledge. Participants draw on how science informs and creates cures in-line with problems within society. Teachers discuss how science changes as a result of changes in the needs of society and how science adapts to these needs.

1: I don't think that once upon a time they decide to see if something is true or not. It really depends on the issues at the time. Like before they had issues with tetanus, cholera and things like that, today we have something different. So what they do and how they study things really depends on the issues present. We can never be sure about the future…about the changes that will influence truth in the future

2: Animals change because they adapt to the environment so if the environment changes which is likely that it will, then all animals will look different to how we know them

1: mhm yes, that's true…never thought about that

(Mixed teacher focus group 2)

While many examples were drawn from present issues within society, it was interesting to note that only one participant gave a different example to explain how different things or in this case, species may look in the future. This example managed to draw in an understanding of the concept from other participants who acknowledged that they never thought about changes in the environment like that.

Participants' discussions on the influence of society on science probed into the societal factors that influence what science studies and its research projects. Scientists own preferences, their experiences and societal issues such as Covid-19 or the issue on vaccines are some examples that participants have mentioned to illustrate how society influences what science studies. In addition to being considered a model of democratic self-government, science has been recognized as an activity that requires and facilitates democratic practices in its social context (Popper 1950, Bronowski 1956). In this view, science is seen as rooted in its societal context but insulated from its effects.

In spite of one's views about the social nature of knowledge, there are further questions that need to be answered regarding what research to conduct, what resources should be allocated to it, who should make such decisions, and how they should be made.This question has been subjected to philosophical scrutiny by Kitcher (2001). Though Kitcher largely endorses his earlier theory of epistemology (1993), in his later work he argues that there is no absolute measure of the significance (either practical or epistemic) of research projects, nor is there any particular standard apart from subjective preference. When there are no absolute standards, Kitcher argued that the only non-arbitrary means of establishing collective preferences is through democratic means. This idea is consistent with participants' own views of the place of science in today's society.

7.3. Scientific evidence derives from both observation and experimentation

Reflecting on scientific methods, participants discussed the standards of both observation and experimentation and how these two distinctive scientific methods work together to derive scientific evidence. Teachers' talk centred on the nature of scientific observation and how it differentiates from other types of observation due to its theory-laddedness. The relationship between observation and experimentation is also discussed in light of how these two methods are utilised in science in both discovery through observation and testing through experimentation.

All discussions within focus group and interviews acknowledged that observation is the first method from which scientific ideas emerge. From such reflection on observation emerged the characteristics of scientific observation, where participants commented that observation carries a lot of meaning. Participants elaborated that observing something does not necessarily mean seeing something directly through sense experience, but also studying objects or phenomena through a scientific lens or through the scientist's own lens.

> *Observation is the basis of science…everything starts with observation, obviously science is not just about observation, but that's where it starts […] When scientists observe, they observe through their own lens…their own ideas, expectations… There is observation but there is prior knowledge too. That effects the way we observe…however in science we test, we don't just observe… it doesn't work that way. There should be proof and explanations of why it happened the way it did…*
>
> *(School B teacher interview)*

The excerpt shows an understanding of the theory-laddedness of observation. This teacher acknowledges that a scientist has his or her own experiences and expectations of the phenomena being observed and that this in turn influences the way something is observed. In this interview, the participant outlined several factors that influences a person's observation, such as experience, knowledge and expectations. Similar understanding was seen in another focus group where participants commented on the meaning attached to observation and how it goes beyond directly observing something with one's own eyes. Similar to the above excerpt, the following excerpt also identifies the need for observation to be followed by experimentation, to prove that what has been predicted through observation is actually correct.

2: I think that observation, it has a lot of meaning to it. It doesn't have to refer to things which we see there and then with just the eyes. I think that it also means studying something, so in a way things have to be observed, for us to believe them because we cannot just assume…

1:Yes and we have to make sense of what we are seeing , so it's not just observation but also thinking about it…I think it depends a lot on how we perceive it

3: In science it's different because it does not depend on perceptions alone. With science something can either be right or wrong… we try it, we test it and it either comes out wrong or right.

2: Yes I agree, because we start from something, like something we have seen and we predict things about it like why it happened and its purpose and then we experiment with it, sometimes it's right and sometimes it's wrong…but there's value in it.

1: I mean it's more than observation…it's not just observation, it's also the knowledge that we have that makes us observe these things…ok scientists observe but what they observe depends on their knowledge…

3: Observation can also be about what is happening around us, what is happening in society, for example Covid-19…

(Mixed focus group 2)

Moreover, the excerpt above outlines participants' thoughts on observation which is specific to what is done in science. Participants mention scientific observation and experimentation as methods which work together to measure whether predictions are correct or not and to provide evidence. Following the idea that the methods utilised in science are different from other disciplines, the excerpt below highlights participants' assumptions on what demarcates scientific ideas from non-scientific ones. They commented that the methods, i.e. observation and experimentation is what demarcates science from other ways of knowing. Participants elaborated on their shared idea that science is not 'just literature' and that it tests ideas for real evidence. While this is not explicitly highlighted in the excerpt, the participants may have attempted to identify scientific ideas as being measurable, which ultimately makes science open to conjectures and refutations. This understanding can be acknowledged in both the excerpt below, as well as a result of scientific ideas being based on predictions which can be either proven wrong or right.

I: How can we differentiate between scientific ideas and non-scientific ideas?

2: They have been experimented on…

3: Not necessarily I think…I think that even observation counts as a study, some things cannot be experimented on…

2: Yeah and what makes science more valid is that it studies through experimentation and observation of artefacts of today and the past and not just literature like other subjects.

1: Yeah I agree

It is also acknowledged in this excerpt that participants identify that some ideas/ phenomena cannot be experimented on, and thus scientists rely on observational studies in the absence of experimentation. While this seems contradictory to participants discussions on the need for both observation and experimentation for scientific study, it is also relevant to point out that participants show understanding that scientific ideas or theories are preliminary and thus have to be tested to provide evidence. In this sense, explanations derived from observation still have scientific value, as one participant in the above excerpt points out, however, it is unclear from this data what makes observation objective in search of epistemic truth in the absence of experimentation. Perhaps, 'testing' can also extend to mean testing through observation as highlighted in the excerpt below. Here, observation is still considered a study or method in itself, with or without experimentation. The notion of discovery through observation is also discussed here.

1: I think that observation is important in every aspect of research be it science or any other discipline

2: It's different… observation in science to other kinds of observation

I: Why's that?

2: I think it's sort of… there's more testing involved. Scientists they don't just observe, they do experiments too… observation I think spikes their interest or it might actually come from their own interest. They observe the things around them and they experiment in relation to what has been observed.

1:Yes, I think so too

(Mixed teacher focus group 1)

The differentiation between scientific observation and non-scientific observation is discussed further in the following excerpt where participants discussed that observation involves experimentation, rationality and an explanation of the findings. One participant suggested a trial and error approach to experimentation, arguing that scientists do not just observe and experiment and get the findings they predicted. Other participants have also acknowledged that science involves more than just experimentation to gather evidence. They argued that giving reasons and explanations is a fundamental aspect of doing science.

1: I think it's mostly about doing experiments and analysing what happened by giving reasons based on tests and stuff like that…

3: Yes, but…I find it hard to believe that scientists just come up with these findings just based on the experiments that they did. I think there is more to that, like I think that there is some trial and error…

4: I think that testing is essential in science. It's all about rigour and being… uhm…it is based on evidence. It wouldn't be science if not.

1: I agree… I think that too about evidence but not sure about it just being based on purely experimentation.

(Mixed teacher focus group 2)

Scientific evidence seems to have a high regard amongst participants. Teachers commented that the methods applied in science show that it has been tested and thus show validated claims. The standards or perhaps the principles applied to scientific methods such as testing in different conditions, causality and rigorous testing, all contribute to the assumptions that scientific testing proves worthy and sufficient evidence.

2: If it's been tested it's been validated

1: It's because science tests their ideas and they are valid as they have been tested in different conditions…they experiment

(Mixed teacher focus group 1)

Consistent with the assumption that participants have about the subjectivity of observation, Hempel (1952) accounted for subjectivity in observation in what he called the 'phenomenon account', in which he describes the observer's subjective experience as one which is conceived through sensations and perceptions. This view of science is consistent with participants' own view on observation and its theory-laddedness.

The relationship between observation and experimentation is also explored in teachers' dialogue. The excerpts from the philosophical dialogues show that participants acknowledge the distinction between observation and experimentation. Additionally, participants seem to acknowledge that testing through experimentation validates what has already been observed. Observation also appears to be pervasive, with participants suggesting that if testing is limited, observation can be considered a study in itself. Philosophers like Latour and Woolgar (1979), and Rheinberger (1997) presented similar arguments about the epistemic distinction when observation is not viewed as pure and direct.

7.4. Science is a process of fitting previous ideas with new ideas together

Prior knowledge and experience were discussed as two defining factors which influence both observation and new scientific ideas. Participants argued that scientific ideas are not a result of discovery by chance, but rather through a process where scientists base their work on previous ideas, to add on to previous knowledge and at times to disprove previous knowledge in light of new findings. Participants defined observation as a process of discovery by which one identifies what knowledge is out there. Some participants also argued that observation is what influences scientists to study. Arguing that observation is the first step in the processfor scientists to formulate their ideas in order to prove if they are correct or not. They arguedthat observation in school science carries a different meaning to that of real science, explaining that observation in school science is the act of directly observing physical phenomena and enquiring about what was observed. Participants conversed on the nature of scientific observation and the role it plays in informing new ideas, as this excerpt below demonstrates.

T2: […] always start like from observing and testing out what needs to be tested

T2: Yes, knowledge is always communicated…it is gained through a process of communication with other scientists, what they have read, like previous knowledge…

T1: There is progress…but still in line with the other ideas, so like we have discussed with Elmar, everything fits sort of together and with new knowledge…new knowledge fits with previous knowledge

(Teacher focus group 1)

The excerpt above illustrates participants' ideas that science is a process of communication through a collaboration of ideas. Participants here acknowledge the different ways by which prior knowledge is communicated to inform the creation of new knowledge. They elaborated on the different ways in which science communicates knowledge, how activities such as interaction with other scientists help generate new knowledge. Collaboration in science was a topic of discussion in all focus groups/ interviews with teachers, with each group acknowledging that sharing of ideas is an essential part of scientific work. The two excerpts below illustrate the importance of sharing ideas to create knowledge.

I think that each and every scientist will have different ideas but together they… first of all they usually see things in a professional sense with the same framework because in reality these would have had the same education in science and secondly they would look at things in a science way and analyse things scientifically. I do believe though that they have different ideas to things, perhaps they do try to eliminate bias as much as possible. I assume that just like any other human though that they do their job…say for example a person, a scientist who has somebody close who died of heart failure then if she or he is doing research on it as a scientist I assume that he or she is more close to the research, more personal in that sense.

(School A teacher 2)

Scientists build on what others have discovered so that eventually they come to a point where they can create something which is useful […], everybody has a different perspective, so one's perspective might help in developing someone else's so that they can create new knowledge. Ideas for example, will influence other ideas

(School C teacher)

In the two excerpts above there is clear recognition of individual experience in the creation of new scientific knowledge. This is not to say that science is just a solitary activity but what the excerpts demonstrate is a recognition of what one scientist's ideas might contribute to the whole and how these ideas relate with other scientific work.

The notion that science is built on ideas by different scientists brings on another perception in how scientific theories operate and how they, together, inform new theories. The excerpt below hints into participants' view that science is a system of ideas from which each part (the idea) is seen in terms of the whole system.

They make sense of the world around them because they understand how something works and they deduce like how other things work as well, based on how everything *works together.*

(Teacher Focus group 2)

In the excerpt above, participants recognise that scientific ideas are hypothesised based on how well these ideas fit with other theories. Once again, participants speak of scientific ideas as being linked together to form a system, a paradigm of understanding. Similarly, one participant describes this concept using a metaphor. She states:

2: Each science comes with their own ideas, their own piece of the puzzle and together they try and fit these pieces together.

3: I agree, scientists they each have their own ideas but somehow their ideas come together because…to a certain extent each scientist will work on their own thing but I imagine that they collaborate together so that they can bring their ideas together

2: Yes, I think they would need to collaborate to fit their ideas together

(Mixed Teacher Focus Group 2)

The concept discussed here is that of science being based on collaborative research activities to ensure the continuity and coherence between theories presented by different scientists. What is distinctive about this view of science is that while science is seen as a collaborative process in the distribution of findings and also in the way that scientists seeks other scientists' work to inform new studies, participants hold the belief that experimental scientific work is still a solitary activity. Viewed in this way, scientific is less about being a social organisation and more of an accumulation of single authorship research findings that are logically and epistemically dependent on each other. This social representation is likely to be developed as a result of the context of discussion.

Participants related to how scientists focus specifically on one small area of research significance and thus this specialisation requires individual effort and experience. Contrary to this, Barlow et al. (2017) stated that a decline of single authorship papers in science was seen in the last ten years. Despite the need for specialised research, science is moving towards becoming more interdisciplinary. A similar statement was made by Anderson (2016), with the stance that scientific research is evolving to become a collaborative effort amongst scientists and also across disciplines.

7.5. Science strives to be objective; truth, whether scientific or otherwise, remains subjective

Following from participants' earlier assumptions on the nature of scientific observation as being theory-ladden and experimentation as a neutralising factor to ensure validity, another social representation can be identified here. From participants' discussions, there is a collective understanding of which areas in scientific studies are subjective and which are more objective. This social representation acknowledges participants' understanding on the idea of truth and how subjectivity influences science regardless of objectivity in the scientific process.

The following excerpt demonstrates thoughts on the individuality in the process of science. Participants acknowledged different ideas and different ways of working amongst scientists. This view depicts science in more subjective terms, consistent with participants' subjective view of scientific observation. Recognition of multiple truths can also be recognised here, where participants elaborated that different people have different realities which effects how they perceive knowledge.

> *Every person is different so you will expect different ways of working and different ideas, not to mention different answers…knowledge. I think that there isn't a right or wrong way, perhaps yes some things make more sense than others…different ideas yes, but we can't just assume that science is the best or the closer to the truth for the sake that it is science…*
>
> *There is truth to Bonnie's card as well, because like we discussed before, there are different realities for different people and I don't think there is just one correct knowledge.*

(Mixed teacher focus group 2)

If it works, it works. We can never be absolutely certain on everything, but science…science can actually observe where the mistake happened… and they should try to prove ideas wrong yes…

(School B teacher interview)

A critical point illustrated in the argument above is the subjectivity of knowledge claims. Participants' purported that while science tries to be objective by testing knowledge claims and ideas (as seen in social representation 4), the product of science, i.e. knowledge is still subject to interpretation. In this sense, all knowledge whether scientific or non-scientific is still subject to different interpretations. This concept is developed more in the excerpt below which highlights the concept of belief when it comes to knowledge claims.

1*: It would be hopeless if we don't believe in anything, I mean ok…some things might not be true because yes things change all the time, but it's all about belief as well. We can believe in anything even if it goes against science, lots of people do. So yes, to a certain point we cannot be sure about anything…it's all about belief*

2: There has to be some truth to things because if not we would never make any progress. Let's say for example vaccines…if the vaccines we are taking are wrong, then what? We are not going to make any progress with science if not…

1: there are just better ideas…I think we generally associate science with the truth because it's built with evidence…

3: yeah it's done through testing… it's not really about beliefs and things like that, I would associate more with evidence.

2: I agree it has more weight when it comes to explanations and we rely on science for most things so I would say yes. Science is not the only way of knowing but regardless it is very well-qualified to provide answers to things which happen in the natural world. Sometimes they can be wrong, still depends on what you believe in…

(Mixed teacher focus group 1)

While this excerpt acknowledges the measures that science takes to be objective, participants elaborated on the fact that despite science's foundation in evidence, it remains tentative in nature due to its subjectivity. There is a slight disagreement in the excerpt about the place of beliefs in science. According to participant one, belief is an integral component of any discipline, including science, since ultimately everything is an idea, whether it is supported by evidence or not. The other participants, however, argued that science is not about beliefs, but about proof based on testing.

This social representation identifies the concept of subjectivity within science, more specifically, the characteristic of subjectivity in truth and knowledge claims. Participants acknowledged the role that belief has in determining what we assign as either true or false. Participants exchanged their views by suggesting examples from current societal issues such as vaccines. They elaborated that individuals can hold different opinions about truth or lack thereof when it comes to determine the truth about matters which are personal and experiential. There is another possible distinction here; true beliefs and true statements. True beliefs are recognised as something which is true based on personal experience and true statements as universal statements of truth. The difference between the two was not made exceptionally clear in participants' dialogues, however based on the examples provided in dialogue, true statements were seen as true based on the recognition that such statements are also true to oneself, regardless if they are true to other people or not. For example, participants explained that personally they do not feel that flu vaccines are useful when it comes to contracting Covid-19. Others have provided similar examples suggesting that while there is evidence that Covid-19 vaccines are safe, they still feel dubious about the effects that these vaccines might have on the person in the future. This notion suggests that there is still a close relationship between true statements supported with measured evidence and true beliefs supported with a person's experience and personal reflections.

7.6. School science reflects general science

On many occasions within focus groups and interviews, teachers reflected on whether school science is representative of general science. In discussions, teachers were asked whether they were thinking of school science or science in general as this was not always very clear. Teachers brought several examples from the science done at school to discuss what they think about the way science operates in real life. In fact, teachers acknowledged that their understanding of science is limited to the knowledge they have as primary school teachers teaching science as a school subject.

As previously discussed, teachers were concerned with their overall understanding of science and this seem to have influenced their confidence in talking about science. It is thus not surprising that teachers seem to rely on the science that they teach at school to rely on what science actually is; its aims, methods and the knowledge it produces.

As evident in children's dialogue, there is similarity between the science that they teach and general scientific work. Teachers commented that the way that science is taught is representative of the way science is done in real life. Notably, this refers to the teaching methods which are 'hands-on' in their approach. However, teachers commented that a hands-on approach to doing science is not always possible as a result of the way science is structured in both the national curriculum and the syllabus. Both documents place a large emphasis on scientific content to be taught in schools.

> *2: Yes I think so. We do try and make it very similar. We try to include… I mean we do try lots of hands-on approaches to teaching science*
>
> *1: I agree, I try to include experiments for every science topic. Sometimes it's not possible though…*
>
> *I: Why's that?*
>
> *1: Mostly because of time, the syllabus is too vast to make time for proper hands-on experiments. Sometimes we just end up going over things quickly because of that*

I: Would you say that doing experiments is reflective of actual science? Do you think that that's what takes place in actual science?

1: Yes I think so. I think it's mostly about doing experiments and analysing what happened by giving reasons based on tests and stuff like that

(Mixed teacher focus group)

Teachers' discussions, as shown in the he excerpt above, demonstrates that while they think that school science tries to be very similar in terms of methods with real-life science, it still falls short in its similarity. This is a result of the purpose and different focus placed on school science and general science, where the purpose of school science is 'for teaching scientific knowledge'. This difference was discussed in more detail in the following excerpt taken from another focus group with teachers. Here, the participants acknowledge what children themselves think on the difference between science as a subject and science as an entity in society. Teachers here argue on the discovery aspect of science and how this seems non-existent in the science classroom. However, not all participants agreed on the difference in methods between the two, with some participants still holding on to earlier beliefs that the science taught in schools reflects real-life science. The disagreement is shown in the excerpt below.

3: I think that there is great difference between the science we do at school and actual science because as children we only teach them what scientists have discovered, we don't actually go over the procedures that they did to come to that conclusion

1: But isn't that what we actually do? We ask children to discuss the results, I mean why things happened the way they did?

3: Yes, but still, there's something different I think about it. I don't really know. I find it really hard to believe that scientists just come up with these findings just based on the experiments that they did. I think that there is more to that, like I think that there is some trial and error to the kind of experiments that they do at school. I don't know, I don't think that the experiments are carried out the same way

2: …we try to involve students in scientific work as much as possible, one that resembles very much the actual science carried out

(teacher focus group 1)

On the distinction between science as a subject and science in general, emphasis was particularly on the scientific methods. Teachers discussed how Bacon's scientific method shown on the cards is a replica of the method used in schools, which follow the same principles. They commented that the same method is the same one which is depicted in any resource used in school science and it is the only method that

1: Yes, I think this is the sort of method I was referring to earlier. I think this is generally the way we do science

2: Yes I agree

3: Usually yes this is the sort of way we do science at school. I think that most textbooks and resources you find all follow this method. Scientific method I think it is

2: Yes

1: Ehe, uhm… yes I think that science is like that usually

I: You mean school science or science in general?

1: Both I think, usually at school we try our best to do experiments like this. Sometimes it's not possible though…

The excerpt above supports the view that the methods used in school science, more specifically, hands-on approaches to do science such as lab work, are principally the same as the methods carried out in real science. Participants' identified that 'the scientific method' is what is usually seen in textbooks and other school science materials and thus what is being taught in the classrooms is a reflection of what is done in general science but on a smaller scale. The excerpt below take from the same participants further supports the belief that children do real science in the classroom. Participants here argue that lack of time and lack of resources are some factors which inhibit children and their teachers to carry out real science in the classroom.

> *2: Yeah, sometimes at school, we just do observations and things like that. I think school science is limited in terms of the science that we can actually do*
>
> *I: Why?*
>
> *2: Because time is limited, resources are not as bad but still…I think time is the most difficult, there is so much content to cover that doing experiments and other hands-on activities are not given as much importance due to how little time we have to cover content*

Despite the lack of confidence in their ability to do science, there was no mention within this dialogue whether this could be a contributing factor that is inhibiting teachers' from teaching and supporting the use of real scientific methods.

7.7. Conclusion

The five social representations identified in teachers' findings provide a good understanding of NoS through the ideas presented, and the interactions of participants with Wonder Wild. Social representations have the potential to offer insight into science education, especially in relation to pedagogical implications for science education.

One major finding to emerge from teachers' social representations is the social aspect of science. Teachers have emphasised the role of society on science, and vice versa, quite explicitly. This concept will be discussed further in the next section which will look into similarities and differences between teachers' and children's social representations, and provide an analysis of concepts discussed amongst children and teachers in relation to the literature, both within philosophy of science and literature within the nature of science.

Chapter 8

Discussion of Findings

8.1. Overview

This study was set out to explore the social representations of primary school children in year 5 and school teachers. The aim of this study was to engage teachers and children in a community of enquiry through philosophical dialogue as a means to explore the hidden assumptions that they have about nature of science (NoS).

The six social representations identified from children's dialogues and the five social representations from teachers' dialogues will be presented and discussed starting with a brief account of any insights into children's and teachers' understandings uncovered in the course of the analysis. This discussion chapter shall then present the common concepts and views amongst teachers and children and how these relate to the literature, particularly in regard to philosophical accounts of science discussed in chapter 2.

In chapter 3 the following questions were posed;

What are students' social representations of nature of science?

2. What are the social representations of nature of science amongst teachers?

3. How do teachers' and students' social representations of science compare?

8.2. Children's social representations

The social representations discussed in chapter seven presented the six social representations that were identified in children's dialogues. The social representations are characterised by optimism and a good level of trust in science. Children discussed several key ideas from the philosophy of science including the prevalence of uncertainty in science, the theory-laden nature of observation, conditions for credibility in science, the role of science in society, limitations of science, and collaboration among scientists.

This study has been able to identify common ideas amongst children about the role of observation and experimentation and the characteristics which define them. Children's ideas on observation seem to be consistent with Hanson's (1958) and Kuhn's (1962) on the theory-ladden nature of observation. The idea is that scientists are motivated by their own beliefs, and interests and thus a prior understanding of concepts might influence observation. On the nature of ideas, students elaborated that scientific ideas are mostly a result of scientists' background knowledge, experience, motivation and interests.

Secondly, children have discussed the empirical nature of science quite extensively. They argued that the experimental nature of science is an important characteristic that demarcates science from other ways of knowing. Children also attributed some factors which provide credibility to observable phenomena. Both repeated testing and agreeableness amongst scientists were identified by children as two factors which provide credibility. Their argument that observable phenomena requires further testing to identify whether the hypothesis, or in children's terms scientists' ideas, is consistent with an inductive view of science. Some scientific knowledge is identified as a result of discovery, i.e. by chance and at other times scientific discovery is also intentional and purposeful. Children were concerned that scientists only share their ideas when testing proves such ideas to be true. These findings share some key features with more traditional ideas about science as listed in

Thirdly, students discussed that since science relies heavily on evidence and not opinions or faith, there are some limitations to what science can actually study and the type of knowledge it produces. Science and religion can thus co-exist by this very nature that science produces a type of knowledge which is different from other disciplines. In relation to this, children argued that science is not the only reliable source of knowledge, other disciplines seek to find truth in a reliable way as well.

Fourthly, children's findings presented some consistency with what scholars such as Lederman (2002) consider as appropriate characteristics to define science in science education, such as the social and cultural embeddedness of science.

8.2. Teachers' social representations

The five social representations discussed in chapter eight provide insight into teachers' ideas about nature of science. Teachers had a high regard for science when compared to other sources of knowledge, with the idea that science aims to meet the demands of society all the while it remains as objective as possible.

They argued that while bias exists as a result of the way science is conducted, mainly the way knowledge is produced and how evidence derived from experimentation is understood, it produces trustworthy knowledge as a result of the testing scientific knowledge has toundergo before it's made public. Despite their high regard for science, teachers stated that scientific knowledge, even with sufficient evidence, is subjective to the individual and society.Anybody can believe whether they accept a scientific claim or not. Thus, while science aims to be universal, this is not always the case as knowledge is understood and perceived in different ways amongst different people.

On the other hand, teacher participants were more concerned with how well science meets the demands of society. They suggested that the social function of science is precisely the main aim of general science. They elaborated on this perception by suggesting that science is progressive as a result of science being able to meet the demands of medicine and technology. On this note they go on to identify scientific ideas or hypotheses as being derived from inquiries, problems and social demands. Based on that, the aim of science is to tackle such demands and improve quality of life. Similar to students, teachers went on to suggest that experimentation is required to test ideas and hypothesis and derive scientific evidence. In terms of progress, similar to the students' ideas, teachers also suggested that new scientific ideas are built on previous ones by relating how new knowledge fits with previous knowledge. In academic terms, peer-reviewing seems to be discussed (although not explicitly) in terms of the collaboration that takes place in science; where scientists come together to make sense of the evidence gathered.

8.3. Common concepts and views among teachers and children and how they relate to the literature

The table below illustrates the similarities and differences between the children's and teachers' social representations of NoS.

Students' social representations	Teachers' social representations
Scientific observation depends on experience and prior knowledge	Science strives to be objective; truth whether scientific or otherwise, remains subjective
Science relies on experimentation to differentiate between which ideas are correct and which ideas are not	Scientific evidence derives from both observation and experimentation
Science is a process of building ideas with evidence and fitting these ideas together in a way that makes sense	Science is a process of fitting previous ideas with new ideas together
Science reduced to its limitations	Science follows the demands of society
There are 'other ways of knowing' besides science , some of which are also as reliable	
School science as a developed body of knowledge intended for the learning process	School science reflects general science

Table 9.3.1. Table of social representations

As seen in the table, there are some over-lapping ideas and perceptions about science amongst children and teachers. The commonly held view of science is that it's an activity by which scientists get to study and understand the world in a precise and reliable way. There is also agreement amongst children and teachers on some characteristics of science, such as scientific methods. Both teachers and children construct science as a process by which scientists discover and formulate ideas based on their observation and prior knowledge and test those ideas to evaluate whether their ideas are true or not. Both groups of participants agree that science is reliable as a result of repeated testing and replicability of experiments and observations.

As previously discussed (refer to chapter 3: literature review), scholars within the field of science education have argued that several features/characteristics of science are important for science education. There is some consensus on these features/ characteristics as can be seen from the table below, however, there is still some disagreement as to the usefulness of these statements for science education. Lederman et al. (2003) project these features and characteristics of science as list of statements, whereas Clough (2007) suggests that such statements could be easily turned to questions to allow for more depth and exploration. On the other hand, Allchin (2012) states that features of science couldn't and shouldn't be reduced to a set of statements and should be science as a 'whole' science. As a result, Allchin produced numerous points which are divided thematically across different scientific concepts. This approach, similar to Clough's questions on nature of science, highlight the extensiveness of nature of science.

The table below illustrates the similarities and differences between the students' and teachers' responses and the literature. In this respect, this table will be used to compare how teachers' and students' fit into the recommendations of the characteristics and features of science compiled by science education scholars.

Students' social representations	Teachers' social representations	Characteristics from literature on NoS
Scientific observation depends on experience and prior knowledge	Science strives to be objective; truth whether scientific or otherwise, remains subjective	Science strives for objectivity but there is always an element of subjectivity in the development of scientific knowledge (Lederman et al., 2003) To what extent are scientists and scientific knowledge subjective? To what extent can they be objective? In what sense is scientific knowledge the product of human inference, imagination and creativity? In what sense is this not the case? (Clough, 2007)
Science relies on experimentation to differentiate between which ideas are correct and which ideas are not	Scientific evidence derives from both observation and experimentation	To what extent is scientific knowledge empirically based (based on and/or derived from observations of the natural world)? In what sense is it not always empirically based? (Clough, 2007)
Science is a process of building ideas with evidence and fitting these ideas together in a way that makes sense	Science is a process of fitting previous ideas with new ideas together	Social interactions among scientists • collaboration or competition among scientists • forms of persuasion • credibility • peer review • limits of alternative theoretical perspectives and criticism • resolving disagreement • academic freedom (Allchin, 2012)
Science reduced to its limitations	Science follows the demands of society	Role of cultural beliefs (ideology, religion, nationality, etc.), role of gender bias, role of racial or class bias (Allchin, 2012)
School science as a developed body of knowledge intended for the learning process	School science reflects general science	How does private science differ from public science? In what ways are they similar? (Clough, 2007)
There are 'other ways of knowing' besides science, some of which are also as reliable		

Table 9.3.2. Social representations in-line with characteristics of science proposed by Lederman, Clough and Allchin

From the table above it can be noted that several characteristics and features of science identified from children's and teachers' social representations conform to the characteristics delegated by scholars such as Allchin, Lederman and Clough. These features include; that science strives for objectivity, the empirical nature of science, social interactions amongst scientists, and the role of cultural beliefs. Teachers and children seem to have quite similar beliefs in some aspects of nature of science, notably about the empirical nature of science. The sections below will critically evaluate common concepts discussed amongst teachers and children, and analyse these concepts with literature from the philosophy of science and relevant literature within NoS where appropriate.

All of whom have identified a number of characteristics of science which they suggest students and teachers should be taught in schools. As can be noted from the literature review in chapter 3, there are some agreed features between tenets suggested by Lederman et al., the questions developed by Clough and the points mentioned by Allchin. For example, all scholars mention the social function of science and science's humane context in the knowledge it produces, i.e. the interests and motivations of scientists. However, as can be seen from the table above, features of science identified in participants' social representations are not all present in the features suggested by all the three mentioned scholars, such as teachers' and children's views on whether school science is reflective of real science, and on the demarcation of science from other ways of knowing.

8.4. Long-standing knowledge and facts are less tentative than newly discovered knowledge

Tentativeness in science is defined as the ability of scientific theories to change in light of new evidence and with the development of science (Johnston & Southerland, 2001). At variance with other studies such as Cakici and Bavir (2012) and Khemmawadee Pongsanon andAkerson (2011) who reported that students and teachers do not have acknowledgement and understanding of the tentative nature of science, students and teachers within this study recognised some tentative characteristics of nature of science. Since children and teachers came up with their own contexts and examples to reach mutual understanding, they communicated which aspects of science are tentative and which areas of science are less tentative. For example, both teachers and children regarded long standing knowledge and facts to be less tentative than newly discovered knowledge.

From discussions, children seemed to appreciate the tentative nature of science more than teachers. This was seen in the way that children were more open to contest scientific knowledge and suggest reasons as to why science changes over time, for example to make way for new knowledge. This could be indicative that children were thinking of ‘real science’ during their dialogue about the tentative nature of science. On the other hand, when speaking of school science, children characterised science as being made up of long-standing knowledge, established, factual knowledge which is less likely to change over time.

Children and teachers within the study further agreed that real science develops alongside society. Children seemed more confident than teachers of the idea that knowledge challenges when new and better ideas come along. Such statements were provided with examples of advancement within science as a result of change in society, such as Covid-19 and the theory of Galileo Galilei which changed how people think about the world. The use of examples in this context were insightful and added a deeper understanding of the meaning being shared in the social representation.

This view of science is in-line with the concept of falsification, whereby old knowledge is replaced with new knowledge when the old knowledge is no longer valid (Popper, 1963). Children were more positive than teachers that the tentativeness of science is a positive characteristic that allows development of ideas and new knowledge. However, it is interesting to note that children also mention that new ideas are based on new ones. While this idea is not excessively discussed in the literature, the development of Kuhn’s theory on paradigms may shed some light to these children’s ideas. Paradigms were referred to by Kuhn as a set of shared ideas about the way something works within a specified context in time. The nature of paradigms set the tone for the development of science and the way science is done and understood. Consistent with this view of tentativeness, both children and teachers agree that science is continuously developing along with society. However, Kuhn argued that such changes, such as a ‘revolution’ and change in paradigm doesn’t happen easily as it takes years for scientists to accept and conform to the new paradigm, with many scientists quite reluctant to adopt new paradigms. This aspect of change and its effects was not a concept which was developed on by either students or teachers. The absence of this might be that participants are not aware of the time it takes for change to happen, or do not particularly see the time it takes as relevant to how accepted such changes are within the scientific community.

According to participants, established theories and facts are less likely to be rejected. That being said, tentativeness was viewed as a positive aspect by which scientists can acknowledge what is true and what is not at a given time. The tentativeness of science was acknowledged as one aspect by which scientists are able to develop their ideas based on previous ones.

From the examples provided in children's and teachers' data, participants' perceptions of tentativeness are context specific. Both teachers and students reason that when there is no direct observation or lack of sensory perception, knowledge derived from such claims is more tentative than what has been observed and tested and has been claimed by various other scientists. While they both hold this view of science, both students and teachers acknowledge that science is still a reliable source of knowledge due to its validity and credibility in measuring knowledge claims and its experimental practices. Credibility as a result of the empirical characteristics of science will be discussed further in section 9.4.3. within this chapter.

Teachers, on the other hand, saw change as happening when, or if society changes, with science, following the demands of that particular point in time. However, as expressed by teachers, acceptance of new knowledge seems to be few and far between, with older and established knowledge taking precedence over new and less established ideas.

In addition to the above concept, it seems that there is more trust in established scientific knowledge, especially from teachers' data. Albeit, the acknowledgment of uncertainty in science, both teachers and children have expressed trust in science, especially in terms of the aims of science and its products/ knowledge. This shows a very positive and optimistic view of science which is surprising considering that Borgerding and Mulvey (2022) reported that teachers primarily did not show high levels of trust in science and scientists. However, levels of trust in the Borgerding and Mulvey's study varied according to the credibility of scientists in the Covid-19 context. They reported that trust in science is heavily influenced by the sources that participants read. This shows a direct link with credibility perceptions of participants in both this study and in Borgerding and Mulvey's study, that credibility is influenced by the understanding of subjectivity in science, good understanding of tentativeness in science and awareness of the empirical nature of science.

Ideas within this study were particularly drawn from the Covid-19 pandemic. This is because most discussions and examples in focus groups and interviews, were based on the medical application of science and its contributions to current societal issues. It also happened that data collection took place during the pandemic itself, therefore, it could be that these were also more familiar examples. This was noted in teachers' expressions of their understanding of science and the examples they provided about the aims of science.

8.5. Despite uncertainty, there is an optimistic outlook on science and trust in science is strong

Children's and teachers' ideas on tentativeness of science indicates differing levels of trust in science and scientists. However, there seems to be a consensus between teachers and children in terms of their level of trust in science. Trust in the knowledge produced by scientists, is held by all participants within the study. Despite participants' acknowledgement of the tentative nature of science, both teachers and students identify a number of hallmarks of trustworthiness in science. These include that science produces reliable knowledge as a result of rigorous testing, validity achieved by justification of knowledge claims, and the idea that science is constantly developing with the needs of society. Such factors of trustworthiness in science are likened to those expressed by Jamieson's et al. (2019) in which trustworthiness in science is linked to its scientific methods. Jamieson et al., as well as Borgerding and Mulvey (2022) have reported that trust in science is influenced by the empirical characteristics of science, these refer to the role of experimentation, repeated testing, and fair tests.

However, from the data there is also greater uncertainty when it comes to new inventions and ideas, especially from medical science. This is brought on by participants suggesting that new information might be less stable as it hasn't been exposed to the test of time. Such thoughts seem to be contradictory to the trust placed in scientific methods. This seems to be more common amongst teacher participants than child participants as a result of the examples that teachers communicated in focus groups and interviews- such as Covid vaccines.

Vaccine confidence suggests to be the overarching epitome of confidence in science, with many participants expressing the need for more validation, information and transparency when it comes to relevant scientific matters and their effects on society. Confidence in science can be quite difficult to achieve when vaccines, such as Covid vaccines were still being developed and tested. However, Nadelson, Jorcyk, Yang, Jarratt Smith, Matson, Cornell and Husting (2014)'s study which took place prior to Covid reported that participants were influenced by information on the negative aspects of vaccines sourced online. They reported high mistrust in science and scientists as a result of lack of public engagement in science and misinformation.

Without bringing the examples of Covid-19 and vaccines, children made the same reflections for science to be more engaging to the public and to be more transparent in their scientific endeavours. Moreover, transparency and validity of justification appear to be the hallmarks of trustworthiness when it comes to participants judging who to trust.

Trust in science is heavily linked with the social and political aspects within society (Volchik & Maslyukova, 2019; Nadelson et al., 2014; McCright, Dentzman, Charters & Dietz, 2013) and might thus be linked to how people feel about these linked concepts that effect trustworthiness- such as faith and politics. Several of the underlying factors that affect trustworthiness in science are heavily linked to culture. Wellcome Global Monitor (2021) reported a number of cultural factors that influence trustworthiness such as confidence in national institutions, access to reliable data, educational attainment, attitudes and religious background. These factors appear to indicate the social, cultural and political aspects that influence participants' ideas of science. Since Covid-19, the Wellcome trust (2021) has reported that there is more appetite for scientific information amongst the general public. However it is concerning that the lowest score of trust amongst the public was found to be amongst the younger generation (those under twenty-five years of age).

It is evident in the data that participants hold science in very high esteem and thus a link can be seen between scientific optimism and trust (Nadelson et al., 2014; McCright et al., 2013). This is warranted by the philosophical conditions under which science works as a process, such as its aims, reliability and validity in society. However, it is concerning that the limitations of science have only been discussed as being specific to what science can or cannot study. No reflections were made on the negative effects of science on society, the ethics and scientific disputes. It is of concern that while participants demonstrate very idealistic and optimistic views of science, they do not show enough criticality when it comes science.

8.6. Repeated testing and agreeableness amongst scientists provide credibility to observable phenomena

In their set of tenets, Lederman et al. suggested that there is no single scientific method. However, as postulated by other research studies, many teachers and students have the perception that science is only conducted using the scientific method supported by Bacon (1996) which is made up of the steps taken to do science. Studies by Carey et al. (1988) illustrate that students have limited understanding of science as an activity and process. Similar studies by Forawi (2018) suggest the same, with students understanding experimental work to be a disembodied process with no ideas or questions to initiate or guide experimental work.

While methods utilised in science were discussed with teachers and students in this study, there is still a gap in terms of what participants identify to be scientific methods. It seems to be common knowledge amongst participants that the scientific method portrayed in Bao Bao's card cannot be the only method which can be used in science. However, both teachers and students were unable to suggest alternative methods used in science, even when invited to do so.

Discussions with students revealed that the scientific method proposed by Bacon is an outline of the scientific study carried out but is not necessarily the method by which scientific ideas are investigated. Children described it as a 'template' by which scientists are able to share their research with other scientists, and with the public, in a clear and constructive way. However, it was also revealed that the method presented only shows a glimpse of all the scientific work that was carried out to be able to get results. On the other hand, teachers' assumptions of scientific methods remained inconclusive. Teachers acknowledged that there might be other methods, however they also stated that 'the scientific method' as proposed on Bao Bao's card is the only scientific method they know, and the one that they use to teach science in schools.

In this social representation, in contrary to earlier works by Hume (1739), children did not find it necessary to separate theory from observation. The philosophy of science has tended to focus on epistemological questions regarding the role of empirical evidence in theory testing. Earlier philosophical work was aimed at conceptually separating theory and observation so that the observation can serve as the sole basis for theory appraisal. While the logic of theory testing seems to be upheld by the participants in the study, as illustrated from the excerpts, participants argued against the objectivity of observation in science. This is contrary to the logic of empiricists which appealed to the objectivity and accessibility of observation reports. However, for participants, genuine credibility of scientific theories is accounted for through repeated testing. Much attention was devoted on the talk of methods in science and how they formulate the process of doing something scientific. This concept has perturbed philosophers of science to question how theory-laden scientific observation can provide objectivity in scientific knowledge (Bogen, 2009). Participants demonstrate understanding that subjective observation is tested under controlled testing to provide an objective measure.

Consistent with the assumption that participants have about the subjectivity of observation, Hempel (1952) accounted for subjectivity in observation in what he called the 'phenomenon account', in which he describes the observer's subjective experience as one which is conceived through sensations and perceptions. This view of science is consistent with participants' own views on observation and its theory-laddedness. Teachers and children both acknowledge the theoretical presuppositions held by scientists and how these impact their observational experience. The image was predominantly discussed in children's focus groups, with children sharing their ideas on how scientists' beliefs, values, culture and their prior knowledge, influences and shapes their work. This is in-line with Kuhn's (1970) statement on the impurities of observation and the influence of theory on observation. However, children's and teachers' talk on the theory-laddedness was not necessarily seen as a bad thing, with participants arguing that repeated testing and agreeableness amongst scientists on the results provides credibility to the observable phenomena.

The relationship between observation and experimentation, the two scientific methods mentioned, were critically explored in dialogue The excerpts from the philosophical dialogues show that participants acknowledge the distinction between observation and experimentation, and additionally seem to acknowledge that testing through experimentation validates what has already been observed. As suggested earlier in this chapter, observation also appears to be pervasive, with participants suggesting that if testing is limited, observation can be considered a study in itself. Similarly, Rheinberger (1997), presented similar arguments about the epistemic distinction when observation is not viewed as pure and direct. Suggesting that children have more appropriate understanding of the characteristics of observation.

Building on the element of creativity in scientific methods, children and teachers thought of science as being both a discovered and innovative entity within society. However, very little talk centred on the role that inference plays in science. Indirectly, children attempted at discussing some features of inferential knowledge such as gravity, by which they argued that scientists cannot directly observe the phenomena but they can rely on their knowledge as well as sense perceptions such as being able to feel the force. They also suggested that explanations for its existence should add-up. This is again in-line with Kuhn (1962, 1970) whose theory on scientific paradigms proposes the idea that theories are consistent with each other in a way that together they stand to reason. However, the idea of observation alone as creating credible scientific knowledge was not a commonly held view amongst children, with the only reference being made in just two focus groups. However, participant data shows that there is a likely relationship between what can be directly observed and what can be inferred from the data. Children and teachers did not directly refer to inference, however they both discussed how some phenomena which cannot be directly observed using the senses can be implied from several different observations as suggested from their examples on gravity and 'the world is not flat' examples.

In relation to this, children also discussed how reasoning plays a role in implying what cannot be directly observed; elaborating that scientists have to think and discuss their studies amongst each other to identify and explain different phenomena. Teachers on the other hand did not elaborate on the difference between observation and inference or the relationship between the two, instead they focused on the role that observation plays in science and the need for science to be factual and empirical. This suggests a more certain and positive view of scientific methods and its product. Teachers' perceptions are in-line with the study made by Cil and Cepri (2016) were they argue that teachers do not hold a distinction between what is observational and what is inferential, and how these influence scientific research.

8.7. Scientific work is embedded in society and thus follows the demands of society in its aims, methods and products

The social and cultural embeddedness of science has been accepted as a feature of science by both Allchin, Lederman et al. and Clough. It has also been discussed quite extensively amongst children and teachers within this study. Participants' discussions on the influence of society on science probed into the societal factors that influence what science studies and its research projects. Scientists own preferences, their experiences and societal issues such as Covid-19 or the issue of vaccines are some examples that participants have mentioned to illustrate how society influences what science studies. In addition to being considered a model of democratic self-government, science has been recognized as an activity that requires and facilitates democratic practices in its social context (Popper 1950, Bronowski 1956). In this view, science is seen as rooted in its societal context but insulated from its effects.

Increasingly, as the reach of science and science-based technologies has migrated into the economy and everyday life of industrialized societies, new attention is being paid to how science is governed. In spite of one's views about the social nature of knowledge, there are further questions that need to be answered regarding what research to conduct, what resources should be allocated to it, who should make such decisions, and how they should be made. This question has been subjected to philosophical scrutiny by Kitcher (2001). Though Kitcher largely endorses his earlier theory of epistemology (1993), in his later work he argues that there is no absolute measure of the significance (either practical or epistemic) of research projects, nor is there any particular standard apart from subjective preference. When there are no absolute standards, Kitcher argued that the only non-arbitrary means of establishing collective preferences is through democratic means. This idea is consistent with participants' own views of the place of science in today's society.

Similarly, as expressed in previous sections, teachers argued that scientific work is embedded in society and thus follows the demands of society in its aims, methods and products. Such perceptions of subjectivity in science have not been yet been reported in any previous studies to date that have looked at teachers' understanding of nature of science.

Moreover, shared understanding could be seen in both children's and teachers' arguments on the subjectivity of knowledge claims. Teachers were more confident than children that truth, whether scientific or otherwise, is subjective. Meaning that knowledge is perceived in terms of the individual's bias, beliefs and values. Teachers argued that while knowledge is intended to be universal, how knowledge is perceived varies from individual to individual. Children on the other hand drew examples from differences in the environment, such as weather, to explain that the aims of science varies from country to country, which effects universality in scientific knowledge.

- Subjective biases based on prior experience and processes of reason employed by those individuals, rather than solely on objective external process
- Observation and theory-ladedness of observation
- Subjective elements are inevitable in scientific inference and need to be explicitly addressed to improve transparency and achieve more reliable outcomes.
- The idea that sound science is free of personal values or subjective assumptions can lead to dangerous biases
- Reproducibility of results of previous experiments. An explicitly subjective stance on scientific inference increases the transparency of scientific reasoning. It also facilitates the verification of scientific claims and contribute to a higher degree of reliability of the conclusions.

8.8. Scientists collaborate to produce new knowledge

The concept of collaboration amongst scientists is one concept within this social representation that has its roots in the philosophy of science. Scientific paradigms, as proposed by Kuhn, are distinctive set of ideas, concepts and patterns that correspond well together. Similarly, in this social representation, participants discussed how scientists piece their own individual work with that of other scientists. In this regard, the concept discussed here is that of science being based on collaborative research activities to ensure the continuity and coherence between theories presented by different scientists. What is distinctive about this view of science is that while science is seen as a collaborative process in the distribution of findings and also in the way that scientists seeks other scientists' work to inform new studies, participants hold the belief that experimental scientific work is still a solitary activity. Viewed in this way, scientific is less about being a social organisation and more of an accumulation of single authorship research findings that are logically and epistemically dependent on each other. This social representation is likely to be developed as a result of the context of discussion. Participants related to how scientists focus specifically on one small area of research significance and thus this specialisation requires individual effort and experience. Contrary to this, Barlow et al. (2017) stated that a decline of single authorship papers in science was seen in the last ten years. Despite the need for specialised research, science is moving towards becoming more interdisciplinary. A similar statement was made by Anderson (2016), with the stance that scientific research is evolving to become a collaborative effort amongst scientists and also across disciplines.

The focus of this social representation was predominantly how previous scientific ideas inform new theories and how it utilises historical scientific episodes to explain contemporary developments within science. This concept could thus be likened to Kuhn's ideas on scientific paradigms. However, in contrast to Kuhn idea that paradigms satisfy scientific change, the concept of tentativeness was not distinctively acknowledged in this social representation.

8.9. There is disagreement between children and teachers about differences in real science and school science

One important finding of this study is the difference in teachers' and children's perceptions and ideas about school science and its similarities and differences to real science. The results indicate that children identify 'real' science as being hands-on, with scientists focusing on discovering new phenomena and testing these phenomena to construct new knowledge. They expressed that in school science the aim is not to construct new knowledge (as no actual knowledge is being produced). Students elaborated that school science is a developed body of knowledge which they have to copy and study to understand what scientists have done in the past. They suggested that school science is intended for the learning process and thus it does not have the creative and innovative component that ‘real’ science seems to have.

Contrastingly, teachers suggested that school science aims to reflect ‘real science’ in terms of the materials used, the mode of delivery and the skills being applied. However, they also argued that whilst school science aims to be a representation of ‘real’ science, there is one difference that is detrimental to school science- the level of skills and knowledge that is appropriate to young students. Moreover, teachers addressed the many limitations of school science, including their own confidence to teach science and the vast syllabus for school science. They argued that as primary school teachers, they are not ‘experts’ in science and this effects their ability to teach scientific skills, more so than teaching scientific knowledge. However, they also argued that the vast school science syllabus does not enable ‘learning by doing’ or ‘inquiry-based learning’ and as a result teachers cannot afford to do ‘proper science’ or real science.

The teachers’ position on ‘hands-on science’ or ‘learning by doing’ does not necessarily suggest a thorough understanding of scientific activities. Hands-on science is often confused with working scientifically (Flick, 1993; Bianchi, 2021). While there are many benefits of engaging children in practical activities, engagement should not be the sole purpose for the practicum in school science. In Children’s Learning in Primary Science Report (2021), Bianchi reported that the practical activities and hands-on work in school science lacks depth and purpose as “children retell the ‘magic’ moments in science learning and aren’t able to explain what they have seen or the concept explored” (p. 6).

Children’s ideas on school science reflect Bianchi’s (2021) position that practical work or hands-on in science is a vehicle for understanding, and not necessarily a destination for enquiry. However, teachers’ perceptions of school science are in conflict with children’s identification of school science, arguing that school science echoes what real science is all about. Suggesting that differences between proper science or real science and school science is mainly resources, experience, knowledge and capabilities of learners.

8.10. Discussion of Wonder Wild resource

This section will discuss the contribution of philosophical dialogue as a research tool for understanding teachers' and children's views of the nature of science. Referring back to the literature review in chapter 3, a variety of assessment tools exist which aim to assess and/or understand teachers' and children's individual perceptions and understanding of nature of science. NoS instruments have been quite popular since the 1960s with many instruments created in response to the increased interest in nature of science in school curricula. This interest was evident in science education research to identify teachers' and children's understanding as a way to improve scientific literacy. As Lederman (1998) observed, a number of instruments have been designed and used since the late 1950s to measure attitudes towards NoS and test skills and understanding necessary for NoS education. Such instruments can be categorised into four main types of quanitative research; questionnaires, inventories, tests and scales, and recently the introduction of qualitative and semi-qualitative research tools, mainly interviews with participants. Organisation of these tools can be seen in the tables below.

Research tool	**Author**
Questionnaires	
Science attitude questionnaire	Wilson, 1954
Views on science-technology-society (VOST)	Hillis, 1975
Nature of science survey	Lederman & O'Malley, 1990
Inventories	
Inventory of science attitudes, interests and appreciations	Swan, 1966
Science Process Inventory (SPI)	Welch, 1966
Wisconsin Inventory of Science Processes (WISP)	Literacy Research Center, 1967
Science Attitude Inventory (SAI)	Moore & Sutman, 1970
Science Inventory (SI)	Hungerford & Welding, 1974

Tests	
Facts about science test (FAST)	Stice, 1958
Test on understanding science (TOUS)	Cooley & Klopfer, 1961
Processes of science test	BSCS, 1962
Tests on the social aspects of science (TSAS)	Korth, 1969
Nature of Science Test (NOST)	Billeh & Hasan
Views of Science Test (VOST)	Hillis, 1975
Test of science-related attitudes (TOSRA)	Fraser, 1978
Test of enquiry skills (TOES)	Fraser, 1980
Conception of scientific theories test (COST)	Cotham & Smith, 1981
Scales	
Science attitude scale	Allen, 1959
Science support scale	Schwirian, 1968
Nature of Science Scale (NOSS)	Kimball, 1968
Nature of Scientific Knowledge Scale (NSKS)	Rubba, 1976
Modified Nature of Scientific Knowledge Scale (MNSKS)	Meichtry, 1992
Semi-qualitative/qualitative	
Views of Nature Of Science (VNOS)	Lederman et al., 2003
Critical Incidents	Nott & Wellington, 1995

Table 9.4. NoS research tools

Several of the tests, scales, questionnaires and inventories used aim to quantify measures of one's understanding. Such tools as listed in the figure above have been questioned for their validity and reliability to test understanding of nature of science (Lederman et al., 1998). For example, inventories are developed around a set of recognised performance standards for which participants' answers are then scored against. Similar to tests, inventories are scored against norm-referenced criteria which do very little in generating deep reflections and participants' perceptions. Moreover, there is still no consensus in NoS, and while there are better reasoned characteristics of science, difficulties in characterising an accurate understanding of science still prevails.

To all intents and purposes, there are several factors which are affecting the validity and reliability of such tests, which as discussed in chapter 3 of the literature review and which will be referred to in this section consist of:

- The content and examples being used in these tests
- Instruments impose examples rather than letting the participants bring their own
- The prior influences of such tests such as researcher's precedential ideas of nature of science
- Emphasis on certain concepts and domains of science
- The language used to construct such tests
- Focus on the attitudes of teachers and students towards science and not necessarily on their beliefs, views and ideas about science.

With increased interest in international assessments, such as PISA and TIMMS (Harlen, 2001; Sadler & Zeidler, 2009), science education has seen an increase in the development and use of research tools for assessment purposes. The critical incidents developed by Nott and Wellington (1995) and the Views of Nature Of Science questionnaire developed by Lederman et al. (2002) proposed a new way of looking at teachers' and children's understanding of NoS as a result of their qualitative element. Qualitative tools and semi-qualitative are being used for classroom practice to offer the possibility for researchers, policy makers and teachers to understand and reflect on understanding of NoS. With less focus on 'measuring' and more focus on 'understanding', the VNOS questionnaire developed by Lederman et al. (2002) has seen a popular use in last two decades with many studies such as those conducted by Akerson et al., (2006), Kapucu et al., (2015), Akerson and Buzzelli (2007) and Bell et al. (2003), all using VNOS to assess students' and teachers' understanding of NoS.

As discussed in Chapter 4 Social representations framework and Chapter 5 methods, the limitations of relying on individual understandings are 1). That responses can be very limited as there is little space for the participant to develop an argument; 2). It doesn't offer reflection on the reasons behind participants' conceptions of NoS; 3). Context is very specific to the one given by the researcher and specific to the examples set in the questionnaires and/or interview; 4). It does not offer participants the space to open up on their own reflections and conceptions of nature of science. The challenges that characterise science are often inaccessible and out of reach of direct perception by an individual. Explaining the above mentioned issues on a lay basis becomes more challenging in an individual-by-individual context.

Wonder Wild was under-pinned by the philosophy of science. The purpose of the tool was to stimulate thinking and facilitate participants' thinking processes. Data from both children and teachers suggest that Wonder Wild was a useful tool to stimulate inquiry, thinking about concepts of NoS beyond the philosophy of science and also offered children and teachers the time and space to contextualise different NoS concepts through their own examples. Such examples are responsible in developing children and teachers' social representations of science. For example, while other instruments offered their own examples to contextualise understanding of NoS amongst participants, this study provided through questions for participants to construct their own ideas based on their understanding, and come up with their own examples. From the data, teachers brought examples from social issues with science such as conspiracy theories and application of science for medical means, while children drew on examples taken from their own science learning such as space and plant science topics. The lack of context in the research instrument also allowed for teachers and children to focus on the aspects of NoS being discussed rather on specific content examples, this allows for a better identification of participants' beliefs through their social representations of NoS.

The major difference of using Wonder Wild from other research tools is that it aims to examine the ways in which teachers' and primary school students make sense of nature of science and these understandings change, shape and develop by acting as a stimulus for sustained philosophical dialogue. The performance of Wonder Wild as a research instrument shall be discussed in this section, however it's crucial to discuss first the approach taken for this study and the role of philosophical dialogue in a community of enquiry.

The network of social representation reveals how teachers and children collectively conceptualise nature of science. The social representations provides an overview of the interactions happening in participants' dialogue. Up till now, only individual measures of NoS have been used. It's also important to look at NoS from a group perspective to evaluate how understanding of NoS is exchanged between participants and the dynamics of the group which present themselves in agreements and disagreements amongst group members. Group dynamics enjoy the added depth which can only be present in dialogue between homogenous participants in a social group. At present, talk on NoS has not been a focus point for children and teachers to talk about in research. A collective approach, such as the community of inquiry adopted in this study, offer a discursive space from which teachers and children can reflect and evaluate on their understanding of nature of science in a homogenous social group. One of the methodological features of such an approach is the possibility for participants to identify and justify reasons behind their arguments and allow participants to draw from a wealth of experiences and knowledge.

Most of the understandings of NoS exhibited by participants in this study developed through dialogue. Furthermore, it is my impression that participants in focus groups seemed to produce richer information than participants who were interviewed. This shows that through a community of enquiry, participants can address philosophical arguments at more breadth as a result of the rich discussions and construction of concepts and perceptions in dialogue with others. By identifying social representations, one can explore the construction of lay explanations for the key concepts being discussed.

The quality of the data reflects the advantage of allowing participants to discuss and elaborate on their own understanding of science. Referring to examples of participants' responses, (see chapter 6 and 7 on social representations), responses demonstrates how dialogue and non-contextualisation in research instruments can give autonomy to participants to construct their own ideas and reflect on their own views about these key concepts of NoS. For instancestudies which used VNOS such as Cakici and Bavir (2012) and Khemmawadee Pongsanon andAkerson (2011), reported that teachers and students have limited understanding of the tentative aspects of NoS. The key concepts studied such as tentativeness of science, were precontextualised into the designers' own understanding of tentativeness and sought to determine participants' understanding of science through their pre-set context.

Another noteworthy consideration is the language used in NoS instruments. As can be seen the examples and language used to inform the questions of the VNOS, can be unfavourable for children to understand and comprehend resulting in lack of validity. For example; words such as theory and inference could be challenging for children. Despite the lack of contextualisation of each key concept in Wonder Wild cards, the questions in this study appear to be written at a level that participants readily understand and engage with, without need for clarification as evidenced in the extracts of dialogue amongst participants.

The difference with Wonder Wild is that while it's grounded in philosophy of science, the research instrument allows participants to openly talk about different aspects of science which matter most to them. However, this can also prove to be a limitation when taking into consideration children's limited experience and knowledge when it comes to doing philosophy and science. For example it can be noted from the use of examples and context of responses from participants that these were very limited. In addition, children's and teachers' experience with doing philosophy was very limited and as such this was a further limitation considering that teachers and children had made no prior reflection on nature of science prior to this study. Secondly, while the above was not so much a limitation in itself, the limited time for each focus group did very little in offering participants the space to explore and expand on their questions and dialogue. This limitation will be discussed further in the concluding chapter where other limitations will be discussed.

While there are challenges and limitations when using such an approach and research tool, Wonder Wild offers a range of facilitation techniques from minimal interaction to more probing. In this study, minimal facilitation was used as a result of the dynamics of online focus groups and interviews. Interaction between participants and participants and facilitator was limited. In fact, it offers the need for little input from the facilitator/ researcher. Nevertheless, there were instances were opportunities for probing would have been useful, such as in dialogue about scientific methods. It would have been beneficial in this case to expand on children and teachers' examples of scientific methods and identify the principles that govern these methods.

One of the main principles of using philosophical dialogue for enquiry as a research tool is that it encourages active participation, i.e. research is done with the participants rather than on the participants. This stresses that rather than 'assessing' what participants know about NoS, it involves arguing about how we understand what we know and how this aligns with beliefs and intuitions. It thus encourages participants to reason, discuss and argue rather thanprovide expected answers. From participant data, dialogue is seen to be collective, supportiveand cumulative. It thus moves away from the idea of one 'correct' version of understanding and that all other understandings need to be corrected. This sets Wonder Wild as a differentqualitative tool which aimed at evoking and discussing social representations at the interactional level between individuals within a social group.

8.11. Summary

This study has identified the present social representations of children and teachers about science. From the discussion of the findings in this chapter, there are several similarities between teachers and children. There is consistency in views on NoS amongst both children and teachers. Such consistency pertains to scientific methodologies; how reliability and validity is achieved, how science justifies knowledge claims and the processes involved in doing science.

Participants have indicated a very positive attitude towards science, with teachers suggestingthat science has a positive impact on society both on the creation of new knowledge and its ability to solve problems within society. A positive attitude could prove to be a limitation considering that participants did not discuss negative effects of science, nor disagreements inscience. Nor did they give due consideration for scientific theories which do not satisfy the needs of society, such as blue skies research.

A lot of the discussion centred on the role of observation and experimentation in science, where children seemed to struggle with the idea of whether scientific knowledge is valid andreliable if produced from observation alone. Additionally, the results clearly show children's awareness of some characteristics of science, namely demarcation of science from other ways of knowing, ideas about scientific methods and the subjectivity of science which seem to contrast with earlier studies suggesting that children do not have the awareness and understanding of NoS.

The distinction between previous studies on the Nature of Science (NoS) and the social representations examined in this study lies primarily in the depth of analysis into participants' responses. This study offers significant insights by delving deeper into how participants form their conceptions of science. Unlike earlier research, which often highlighted a general lack of understanding among students regarding the subjectivity inherent in science, the current study reveals that participants recognize situations within scientific practice where subjectivity is more evident. This understanding acknowledges science as a human endeavour—despite its rigorous methodologies and precise measurements, it remains influenced by human interpretation, assumptions, and expectations.

The findings of this study illustrate that a more nuanced approach to researching scientific perceptions can lead to richer insights into both teachers' and children's developed and insightful ideas about science. By focusing on the social representations of science, this research underscores the complex, multifaceted nature of how science is perceived and taught, suggesting that these perceptions are shaped by deeper cognitive and cultural factors than previously understood. This approach not only broadens our understanding of NoS but also enhances the educational strategies that can be employed to address these perceptions effectively in science education.

Similarly, this study reveals an evolving understanding among children that scientific methods are not as linear as previous studies have suggested. This insight emerges from how children describe the activities conducted in school science—which are often portrayed as following a linear sequence—and contrast this with their perceptions of how scientific research is conducted in 'real life'. Children recognize that real scientific inquiry often adapts and evolves in response to new information, reflecting a more dynamic and iterative process.

A nuanced approach such as the one taken in this study suggests that children are beginning to grasp the complexities of scientific investigation beyond the simplified models typically presented in educational settings. It highlights a discrepancy between the structured, step-by-step approach to science that schools often teach and the more fluid, responsive nature of professional scientific research. Acknowledging and addressing this disparity in educational practices could lead to more effective teaching strategies that better prepare students for the realities of scientific work, fostering a deeper appreciation for the nature of scientific enquiry. Social representations have important implications for developing children's and teachers' understanding of science and also have the possibility to guide reform of science education.

The next chapter will conclude this dissertation by highlighting the implications of this study based on the findings and discussion. It will also acknowledge and discuss the limitations of the study and make suggestions for future research within the field. Considering the aim of the study, the concluding chapter will set out recommendations for policy makers to influence practice within science education.

Chapter 9

Conclusion

The purpose of this chapter is to conclude this study on children's and teachers' social representations of science by summarising the main findings in light of the research questions as well as to discuss some of its limitations. I set out to explore what children and their teachers believe about science, its aims, processes and characteristics to understand their perceptions and understanding of science. I have argued that children as a social group have common ideas about what science is and how it functions in society. Similarly, teachers have their own ideas and beliefs about science as evident in their discussions on science. I will discuss my original contribution to knowledge: i). an understanding of children's and teachers' social representations of science, ii). the development of a novel way of understanding children's views about science which is not based on a written assessment, predetermined prior knowledge. The conclusions from the study will be followed by a discussion of the implications of this study, including those for curriculum planners, teachers, and researchers. Furthermore, recommendations for future research will be considered.

9.1. Restating the main aims

Till present, this study is the first study to consider children's and teachers' social representations and doing so using a community of inquiry as a method of data collection. The study set out to address the two main research questions relating to the understanding of science amongst children and teachers in Malta:

1. What are children's social representations of science?
2. What are teachers' social representations of science?
3. Are there similarities between teachers' and children's social representations?

The philosophically grounded research methods used in the study, which supported a collaborative form of inquiry into children's and teachers' assumptions about science, their interaction with science and how their perceptions have developed from their discussions, enabled me to find out what social representations children and teachers hold about science.

9.2. Summary of main research findings

The data based on social representations from teachers' and children's philosophical dialogues led to the following conclusions:

1. **What are children's social representations of science?**

This study was successful in exploring the understanding of NoS amongst school children in Malta in the form of six social representations that have recognised from children's data. The use of Wonder Wild as a stimulus for philosophical dialogue prompted children to explore their understandings of science in terms of the methods used for creating knowledge and the nature of such knowledge. This allowed me to identify assumptions that they seem to have about science and the views presented in the cards – i.e. their representations of science. The focus groups using philosophical dialogue offered children the opportunity to share and develop their views about science.

Children's social representations are characterised by some big ideas from philosophy of science; these include concepts such as demarcation of science, the empirical nature of science, and the processes and methods of science.

The following six social representations were identified:

1. Scientific observation depends on experience and prior knowledge
2. Science relies on experimentation to differentiate between which ideas are correct and which ideas are not
3. Science is a process of building ideas with evidence and fitting these ideas together in a way that makes sense
4. Science has limits to what it can do
5. There are 'other ways of knowing' besides science, some of which are also as reliable
6. School science as a developed body of knowledge intended for the learning process

Children emphasised the subjectivity of science, especially in terms of motivations of scientists and the presence of theory in scientific observation. However, children exhibited more confidence in scientific knowledge than on the processes of science. Notably, on the subject of scientific methods, children seemed confused as to what kind of work scientists do and the sort of principles that govern scientific methods. Perhaps unsurprisingly, children used examples from school science to explain their ideas, using their education to make sense of the stimulus cards. This could suggest that children don't learn much about how scientists work beyond the school context.

2. What are the social representations of nature of science amongst teachers?

The study also aimed to explore teachers' understanding of NoS. Five social representations from teachers' analysis of data were identified. These are:

1. Science strives to be objective; truth whether scientific or otherwise, remains subjective
2. Scientific evidence derives from both observation and experimentation
3. Science is a process of fitting previous ideas with new ideas together
4. Science follows the demands of society
5. Science follows the demands of society

Surprisingly, teachers have a more optimistic view of science than children. They understand that science aims to meet the needs of society, therefore regarding science to be a powerful and helpful entity to fix problems within society and make it a better place.

With the exception of discussion on local issues (such as Covid and administration of vaccines), teachers' examples of the ideas discussed seemed to be shy of any contextualisations or examples.

Furthermore, teachers expressed confidence in how science meets society's needs but less confidence in teaching science which is a concerning result from this study.

3. How do teachers' and students' social representations of science compare?

The study found few differences between teachers' and children's social representations of science. Several cross-themes can be noted from the social representations of children and teachers.

The major difference that could be identified between teachers' and children's views of science is the acknowledgement of differences between science, and science in education amongst children. Children seem to see a vast difference between real science and school science. The reasons attributed to this seem to stem from the idea that the aims and purposes of real science differ from real science, and thus, the practice of science is also influenced. According to children, whether science is deductive or inductive, is entirely based on the aim of the scientific activity. With science for education being less tentative than real science itself, children have the perception that science within education is inductive, unlike real science.

The other difference that could be identified between teachers' and children's representations is the idea of limits in science. It was expressed in children's discussions that there are several limits when it comes to science, mostly pertaining to what happens in the mind, future occurrences and life beyond death. Unlike children's discussions, teachers did not make an extensive reference to the limits of science, with most teachers' only agreeing that science is able to answer many questions about the world around us.

These findings are useful to understand the sort of assumptions that children and teachers have about science, to identify any challenges or concerns which impede science learning, to resolve any unhelpful representations that children and teachers might have about science and thus to enable policy makers to develop a science programme which is meets the needs of the learners.

The social representations explored are novel in that they identify children's and teachers' views about science without any written assessments and prior knowledge, and instead allows children and teachers to draw on their own experiences and ideas. This means that there is value to the knowledge that they come with, rather than what they regurgitate. Effectively, social groups such as in the case of teachers and children, have some shared understanding when it comes to science due to some similarity in their experiences. For example; it is evident in the range of examples provided that teachers used schools science and recent media coverage as a context for the development of their views.

9.3. Limitations of study

A number of limitations to this study are a result of the timing of data collection. This was just beginning as lockdowns were imposed in Malta. I had travelled to collect data and was unable to enter classrooms as planned, and had to quickly adapt my study to be conducted remotely. This had an impact on the quantity and quality of data collected.

i). Sample size

Albeit small, the sample size included each type of school; catholic, state and independent, from different demographics within the small island of Malta. As a purposive and representative sample, it reflected the specified characteristics of the study. Despite challenges with accessibility as a result of Covid, the small sample size allowed for new and rich data, small enough to support the depth of the analysis that is optimal for this inquiry.

ii). Size of each focus group

Three focus groups were quite large, averaging around twelve students in each group. Focus groups were not intentionally planned to be of such a large size, however preventive measures due to Covid, such as protective 'bubbles' did not permit children to mix with another class. This resulted in all children within the bubble to be present for each focus group.

iii). Online data collection with interaction mediated through the teacher

Moreover, focus groups with children and interviews and focus groups with teachers had to be conducted online. Due to the nature and ideal structure for philosophical dialogue this proved to be quite challenging. Ideally, participants would have been seated in a circle with access to cards for which they could have handled and passed around each other, or have access to their own devices.

iv). Wonder Wild cards and the depth for discussion

There is also a limitation in the design of Wonder Wild, which addresses only limited aspects of the NoS. Given the long and rich history of the philosophy and sociology of science, and the limited time available for data collection, this was unavoidable. Some important aspectsof science were absent from the cards related to social and economic practices such as open debate of ideas, peer review, funding, technology, and public scrutiny. In spite of the fact that ideas like these are more closely associated with the sociology of science than its epistemology, they nonetheless affect views on scientific knowledge. A follow up study could involve the design of Wonder Wild cards to explore these issues.

Nevertheless, the cards were carefully designed to open discussions and draw on the any aspects related to participants' own experiences and can be used in other contexts to understand children and teachers' views in relation to other aspects.

In terms of applying the Wonder Wild cards and the use of philosophical dialogue in other contexts, there is a need to ensure the researcher and focus group facilitator is trained in how to manage philosophical dialogue. This training is likely to include how to generate initial ideas and probe response.

v). Limitations due to Covid

As a result of the pandemic children had to stay in their respective 'bubble' and could not interact with other children. This resulted in children sharing and looking at one screen during the focus groups and less interaction with the other participants in the group.

Limited facilities such as the absence of individual screens with which the children could have used to communicate with the facilitator/researcher in focus groups, was a limitation in this study.

Nevertheless, under challenging circumstances, this study reached all the different types of schools in Malta; catholic, state and independent. As well as managed to explore rich data by developing a good research tool that aimed at drawing on participants' own experiences.

9.4. Recommendations for future research and practice

One of the immediate tasks following the end of this study would be to carry out research, as was intended with smaller focus groups in-person. As discussed in the limitations of this study, ideally, focus groups are carried out with not more than six students to allow for participants to discuss in more depth and breadth the ideas presented.

Noting on teachers' data, an improvement with Wonder Wild would be useful with the introduction of a new card. Teachers perceptions are far removed from scientific aims that do not fit with their perceptions that science only follows the demands of society. For this reason, a new card which presents scientific work which goes beyond scientific aims to meetthe needs of society (such as blue skies research) could be useful. This might allow participantsto discuss the idea further and consider other possibilities in terms of scientific aims.

Finally, it would be interesting to consider social representations of nature of science across different countries and age groups to identify any trends, or perhaps similarities or differences in terms of culture, beliefs and age when it comes to nature of science. For example, Kang, Scharmann and Noh (2005), noticed fundamental differences between western and non-western students in their views of science and the epistemology of scientific knowledge. An interesting concept would be to identify variances or similarities in social representations about nature of science across different cultures, especially where indigenous knowledge meets western knowledge. This line of research could identify differences and similarities between cultures and different ways of knowing.

The research reveals a number of implications for practice. The study reveals the need for education to equip both children and teachers with a better understanding of how scientific knowledge develops and how scientists work. This might include more examples of how different types of scientists work to move away from existing representations that scientists discover and experiment.

A second implication for practice relates to the use of the Wonder Wild cards. Whilst I used them as a research instrument, they have the potential to be used as a pedagogical tool to enable teachers to understand what children understand about how science works. Used in an educational context, the teacher could play a more active role in encouraging students to explore and refine their views for example by introducing with historical and contemporary scientific episodes. Students' responses in the focus groups, as well as their attitudes, suggest that Wonder Wild could provide teachers with useful information about their students' understanding in the classroom. Teachers might gain valuable insights into their students' thinking from individual questions, which could be used as stimuli to elicit discussions in class.

The perceptions and assumptions children and teachers have, suggest that professional development for primary school teachers in primary science will be an asset in supporting teachers in their understanding of science, their engagement and interaction with science and in their pedagogical practices. Having an understanding of children's and teachers' social representations based on their own experienced and assumptions helps in constructing and developing science programmes which meets the needs presented and which allows for development in children's understanding of science. There is a great need to foster understanding of, and about science and promote scientific literacy for both adults and children alike.

The study also hints at the significant role that language and cultural influences play in discussions about science, suggesting an intriguing avenue for further research. It would be valuable to explore how language shapes the way we talk about science and subsequently influences both the teaching and learning processes. Delving into the nuances of language use could uncover how specific terminologies, metaphors, and linguistic structures impact students' and teachers' understanding and communication of scientific concepts.

Additionally, examining the effects of bilingualism on the teaching and learning of science could provide deeper insights into cognitive and linguistic flexibility in scientific contexts. This research could focus on how bilingual individuals navigate and reconcile scientific terminology and concepts across languages, and the potential cognitive benefits this dual linguistic framework offers. Particularly, it would be interesting to analyze how language proficiency and choice influence the depth and nature of philosophical discussions in science, potentially affecting critical thinking and reasoning in philosophical discussions about science. Such studies could not only enrich our understanding of the cognitive and linguistic complexities in science education but also inform more effective pedagogical strategies that accommodate linguistic diversity in the classroom.

This study has contributed to an original research tool and method that explored both teachers' and children's understanding of science through their social representations of science. Each visual within this study opened a discussion about different aspects of science. Children's concepts of science are said to be the building blocks of their ideas and beliefs. They make up children's mental and social representations where these concepts can exist both in the mind of the child but initially they exist through social constructs (Driver, 1985). These notions ensue in speech and thought and thus can be understood through discussion. With social representations theory, children and teachers were able to reflect on their own thinking. The values, ideas and beliefs that are shared by children can help scaffold how children re-construct reality and form the background of children's nature of science (Driver,1985;1989; Bachtold, 2013).

The social representations explored in philosophical dialogue gathered the shared understanding that teachers and children have in relation to different aspects of science- those in which they have drawn on in their discussions about science. The strength of the study is the way in which participants were given the opportunity to consider alternative ideasby regarding their experiences with science in school science and beyond. Interestingly, understanding how children and teachers make meaning about science based on their own experiences allowed for a privileged position in producing social representations that richly offer the assumptions that these two social groups have about science. It is of value to utilisethese assumptions and the values of science that children and teachers share to better support their teaching and learning.

A more accurate understanding of science is in everyone's interest and thus it is highly sought by both the scholarly community and those involved in primary education (Matthews, 2012). It is desirable that children have a solid foundation to build up and articulate on the science content that they are taught in schools (Obe, 2018; Allchin, 2012). As has been mentioned by Matthews (2012), nature of science views of the individuals involved are highly dependent on their experience and their profession. Teachers will have a set of values, beliefs and ideas about science coming from their experience of being both 'learners of science' and now 'facilitators of science' (Bybee, 2014); sharing their own values and beliefs about science to the learners involved, likewise with children their experience with science is often that of being ‘learners of science’ and thus it would be highly unlikely that children have a very informed view of science (Bachtold, 2013).

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Appendix

Wonder Wild Cards

"SCIENCE IS EVERYTHING WE CAN SEE WITH OUR OWN EYES. WE TEST IT TO CHECK IT IS TRUE"

Do you only believe what you can see?

You can't see gravity. How do you know it exists?

Where does scientific knowledge come from?

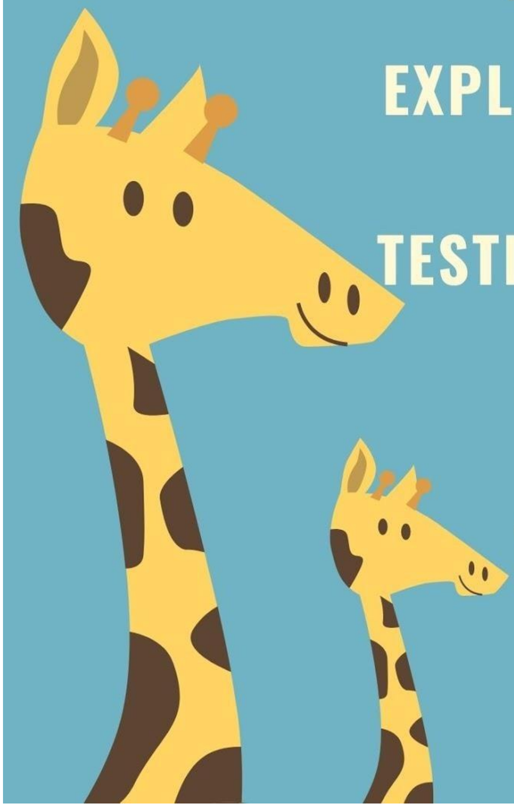
Bao Bao says that there is a specific way of doing science

1. Observation
2. Guess about what we think
3. Test to see what happens
4. Share our results.

Do you think that science always follows this method?

Can science prove everything?

How many times does something need to be proved to be scientific?

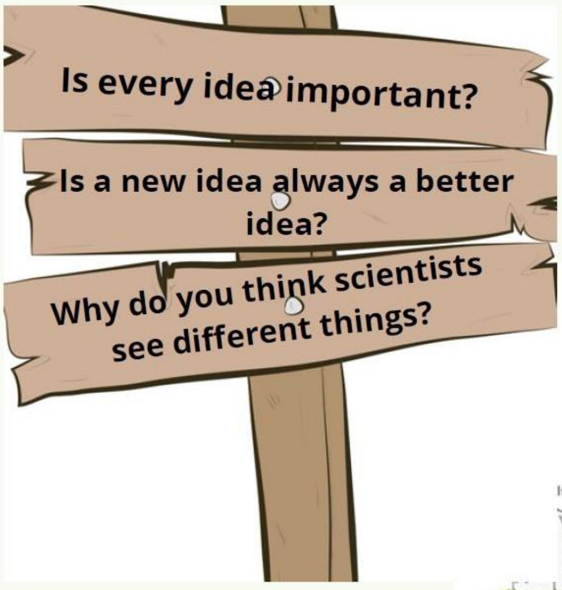


"ONLY STATEMENTS AND EXPLANATIONS THAT CAN BE SHOWN TO BE FALSE BY TESTING CAN BE SCIENTIFIC"

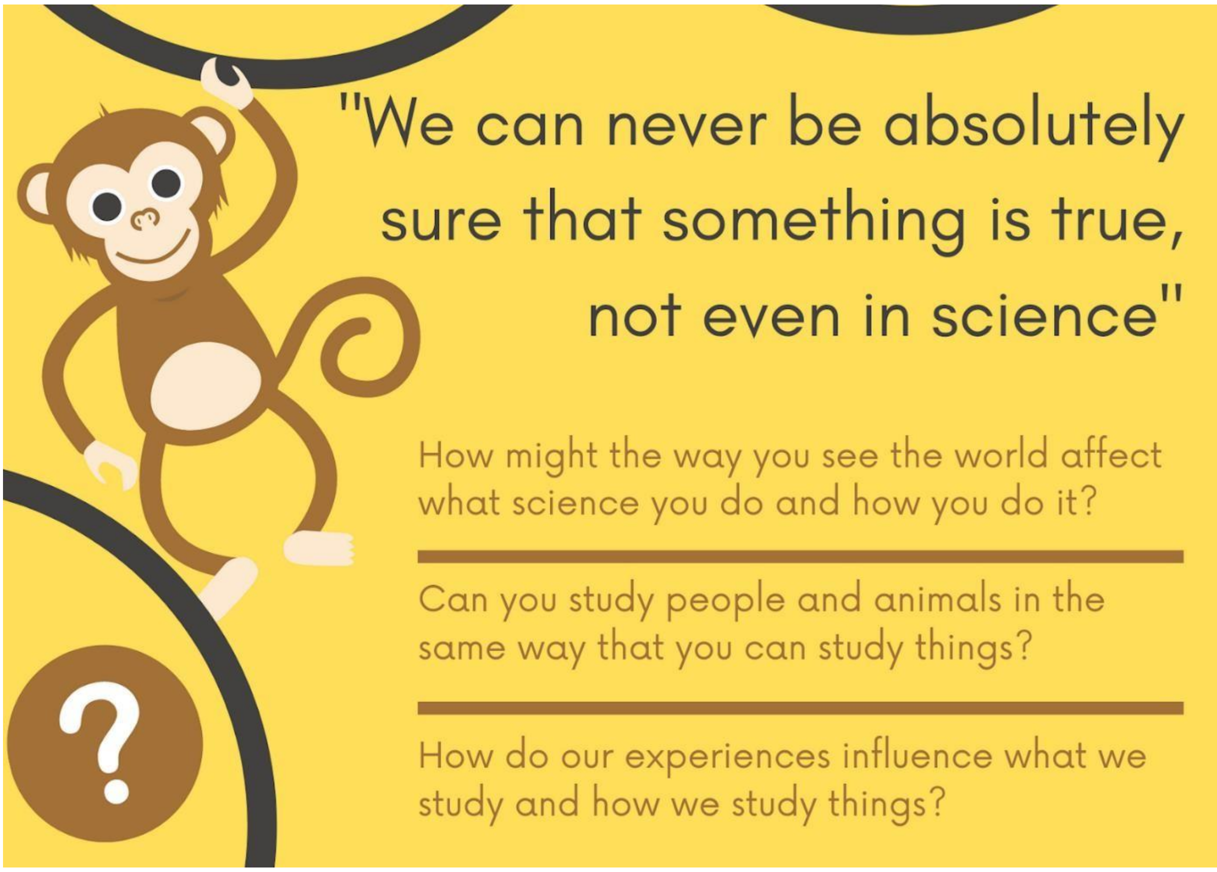
Do you think that every scientific idea can be proved false?

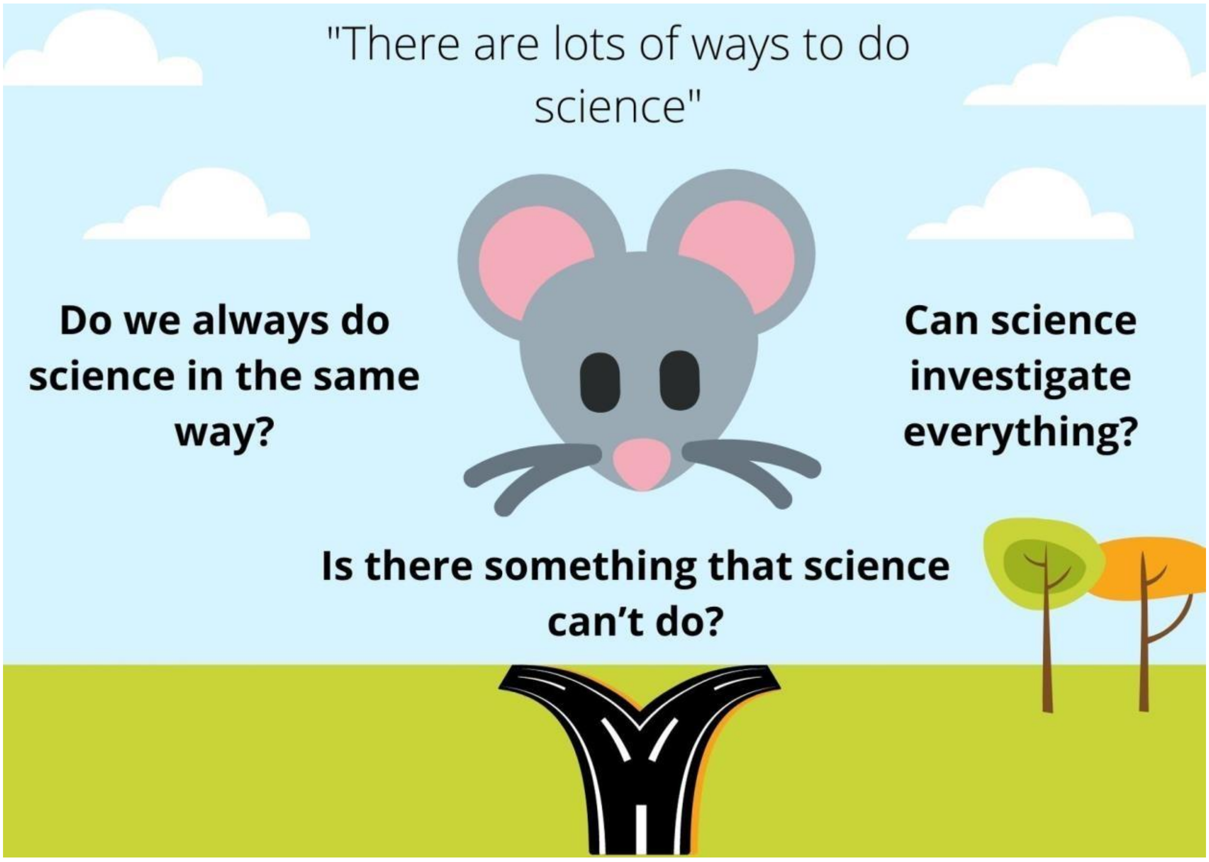
What happens when ideas are proven false?

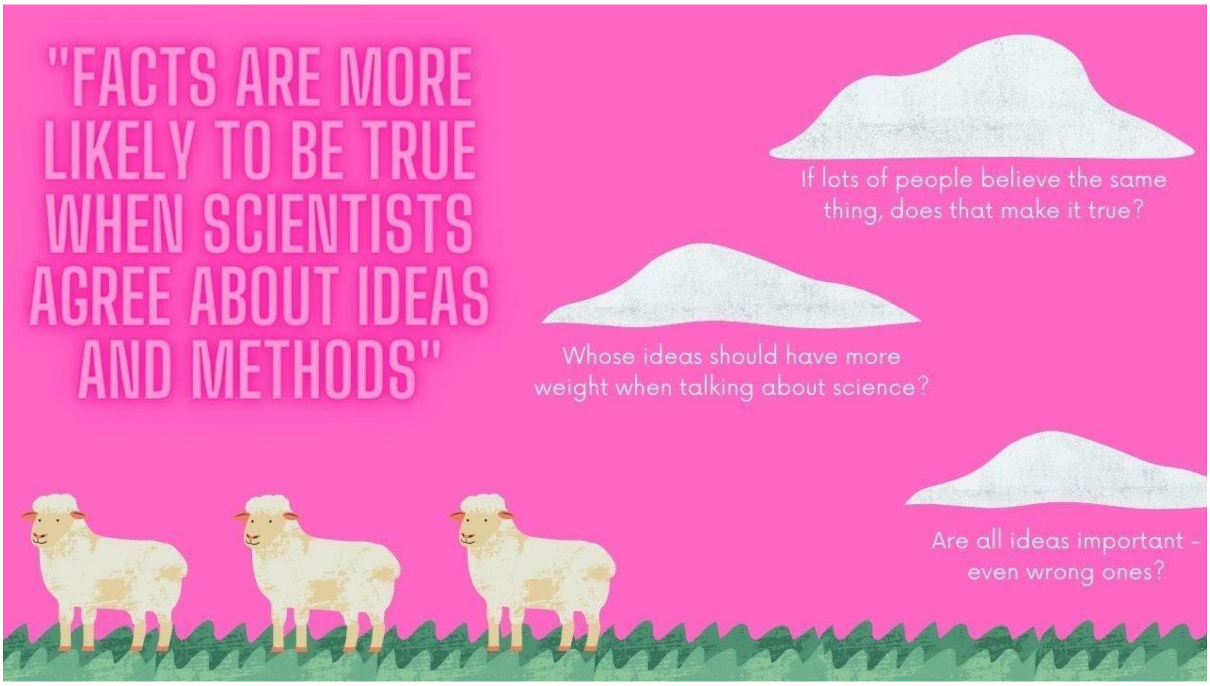
Should scientists set out to prove themselves false?

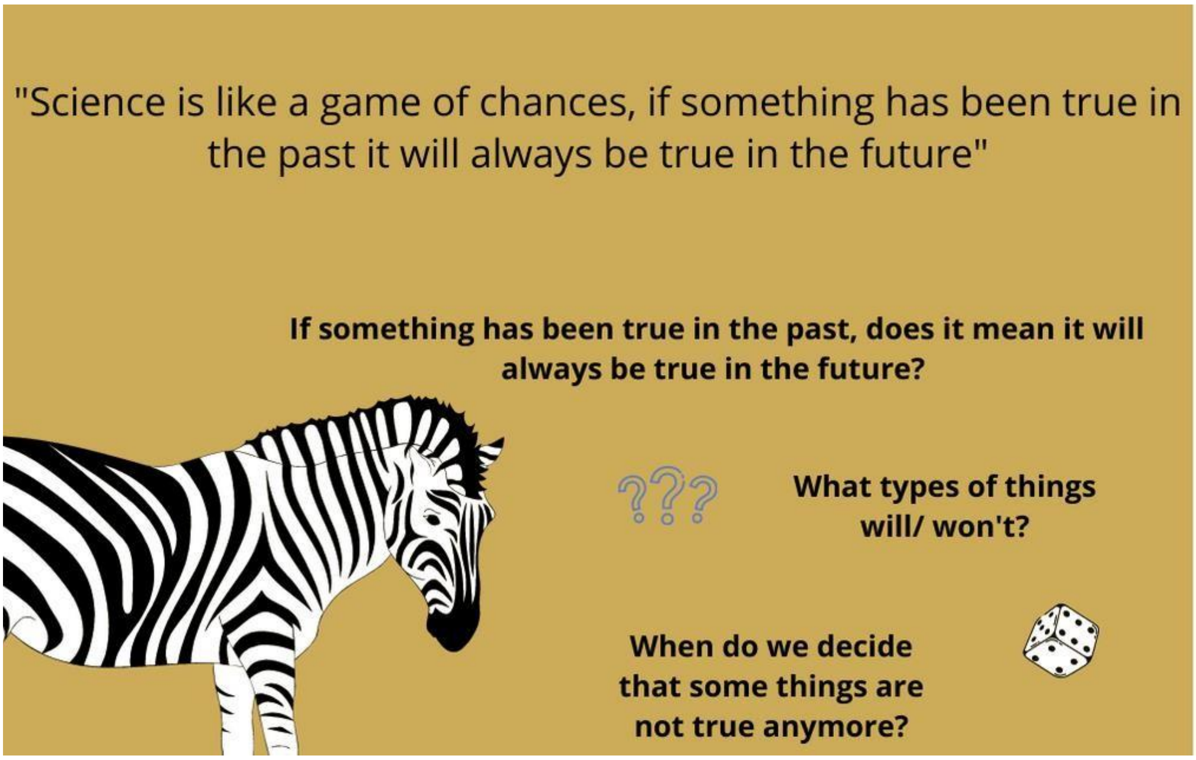


Elmar believes that science is like an elephant-sized puzzle where different people study in their own way which then changes when something doesn't make sense anymore


"We can never be absolutely sure that something is true, not even in science"
How might the way you see the world affect what science you do and how you do it?
Can you study people and animals in the same way that you can study things?
How do our experiences influence what we study and how we study things?


"There are lots of ways to do science"
Do we always do science in the same way?
Can science investigate everything?
Is there something that science can't do?


"FACTS ARE MORE LIKELY TO BE TRUE WHEN SCIENTISTS AGREE ABOUT IDEAS AND METHODS"
If lots of people believe the same thing, does that make it true?
Whose ideas should have more weight when talking about science?
Are all ideas important - even wrong ones?


"Science is like a game of chances, if something has been true in the past it will always be true in the future"
If something has been true in the past, does it mean it will always be true in the future?
What types of things will/ won't?
When do we decide that some things are not true anymore?