ENHANCING PRE-SERVICE SCIENCE TEACHERS’ UNDERSTANDING OF HOW SCIENCE WORKS IN SOCIETY

THE ROLE OF ECONOMICS AND ENTREPRENEURSHIP IN NATURE OF SCIENCE

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Annem’ e ve Babam’a…
ABSTRACT

Recently, particular social aspects of nature of science (NOS), such as Economics of Science (EOS) and entrepreneurship in science, started to gain attention (Erduran and Dagher 2014a; Kaya et al. 2018b). Today’s young people are required to improve their 21st-century skill set, such as economic and entrepreneurial skills, to realise their full potential, get ready for the challenges of higher education and career development (Department of Education and Skills (DES) 2016; Volkmann et al. 2009). However, the research investigating pre-service science teachers’ (PSTs) understanding of EOS and entrepreneurship within the NOS context and on how science works in society is scarce. It is not surprising then that the practical applications, such as lesson resources and teaching materials, are rare.

The current study aims to identify Irish PSTs’ understanding of EOS and entrepreneurship within the context of NOS and science education, and how science works in society. By adopting the extended Family Resemblance Approach (FRA) as the theoretical framework (Erduran and Dagher 2014a), the author conceptualised EOS and entrepreneurship as part of the social aspects of NOS (called contemporary social aspects of NOS later), proposed a framework (the SAMI cycle framework = State/government-Academia-Market-Industry relationship) illustrating how science works in society and re-defined entrepreneurship within the context of NOS. The author also developed and applied an intervention with PSTs on both a continuous and once-off basis in Ireland. PSTs’ understanding of these three concepts (EOS, entrepreneurship and the SAMI cycle framework), their views of inclusion of these concepts in the Junior Cycle Science Specification (JCSS) and their experiences across the current study were investigated through different research instruments, such as interviews, questionnaires and lesson activities.

Thematic analysis, network analysis and Wilcoxon signed-rank test results suggested that there were improvements in PSTs’ understanding of the concepts of EOS, entrepreneurship and the SAMI cycle framework following engagement in the study. While PSTs initially showed a fragmented understanding of EOS and entrepreneurship, post-intervention they displayed a more holistic view of these concepts. Furthermore, the majority of PSTs supported the inclusion of these concepts in the JCSS, although state assessment continued to influence their thinking. Implications for pre-service teacher education and science education are discussed, and investigation of the inclusion of technology in EOS in NOS or the SAMI cycle framework, the implications of the contemporary social aspects of NOS and the SAMI cycle framework to utilise STEM education and engineering education, and these concepts at all levels of education were suggested for future directions.
AUTHOR’S DECLARATION

I declare that the work in this thesis was carried out in accordance with the requirements of the University’s Regulations and Code of Practice for Taught Postgraduate Programmes and that it has not been submitted for any other academic award. Except where indicated by specific reference in the text, this work is my own work.

Work done in collaboration with, or with the assistance of others, is indicated as such. I have identified all material in this thesis which is not my own work through appropriate referencing and acknowledgement. Where I have quoted from the work of others, I have included the source in the references/bibliography. Any views expressed in the dissertation are those of the author.

SIGNED: ………………………….

DATE: ……………………………..
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<td>DES</td>
<td>Department of Education and Skills</td>
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<tr>
<td>EOS</td>
<td>Economics of Science</td>
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<tr>
<td>ESGI</td>
<td>European Study Group with Industry</td>
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<td>FOS</td>
<td>Features of Science</td>
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<td>FRA</td>
<td>Family Resemblance Approach</td>
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<td>JCSS</td>
<td>Junior Cycle Science Specification</td>
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<td>JC</td>
<td>Junior Certificate Examination</td>
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<td>LC</td>
<td>Leaving Certificate Examination</td>
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<td>NOS</td>
<td>Nature of Science</td>
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<td>NSF</td>
<td>National Science Foundation</td>
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<td>PST</td>
<td>Pre-service Science Teacher</td>
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<td>PSTE</td>
<td>Pre-service Science Teacher Education</td>
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<td>R&amp;D</td>
<td>Research and Development</td>
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<td>RQ</td>
<td>Research Question</td>
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<td>SIS</td>
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<td>SOL</td>
<td>Statements of Learning</td>
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PART ONE:
INTRODUCTION AND
LITERATURE REVIEW
1 CHAPTER ONE: INTRODUCTION

Nature of Science (NOS) and its importance have been studied for decades by many researchers (e.g. Erduran and Dagher 2014a; Lederman et al. 2002; Kimball 1968). Recently, social aspects of NOS started to gain attention, for example; perspectives from the economics of science (EOS) and entrepreneurship (e.g. Allchin 2011; Erduran and Dagher 2014a; Kaya et al. 2018b). Entrepreneurship and EOS became targeted skills of the 21st century in science education to make young people realise their full potential (Anderson et al. 2017; DES 2016; Volkmann et al. 2009).

Therefore, the current study aims to develop and explore pre-service science teachers’ (PSTs) understanding of the role of EOS and entrepreneurship in nature of science (NOS), and how science works in society. The place of EOS and entrepreneurship within the social aspects of NOS are investigated, and a new framework illustrating how science works in society - the SAMI cycle framework - is proposed. These concepts (EOS, Entrepreneurship and the SAMI cycle framework) are then integrated into a pre-service science teacher education (PSTE) programme in two different ways, i.e. on a continuous basis over a period of six weeks and a once-off basis in the form of a two-hour workshop. Therefore, the current study explored PSTs’ understanding of these concepts before and after this programme and their educational views of integrating these concepts into the science curriculum in Ireland, which is called the Junior Cycle Science Specification (JCSS).

This chapter sets out the purpose and objectives of the current study as well as the significance of and rationale for conducting research on NOS, EOS and entrepreneurship within the context of the JCSS and teacher education.
1.1. THE PURPOSE AND OBJECTIVES OF THE CURRENT STUDY

Economic and entrepreneurial perspectives and understanding of how science works in society are important in nature of science (NOS) and science education (Allchin 2014; Deveci 2016; Erduran and Dagher 2014a; Irzik and Nola 2014; Kaya et al. 2018b; Matthews 2012). Nevertheless, the research on PSTs’ understanding on these concepts and their practical applications, such as lesson resources and teaching materials for particular social aspects of NOS, such as economics of and entrepreneurship in science, are scarce (Allchin 2011; Jimenez-Aleixandre 2015; Peters-Burton 2012). In order to address this gap, the purpose of this study is to focus on pre-service science teachers’ (PSTs) understanding of economics of science (EOS) and entrepreneurship within the context of NOS and science education, and how science works in society. Within this focus, the current study:

1. conceptualises EOS and entrepreneurship as part of the social aspects of NOS (called contemporary social aspects of NOS later) and proposes a framework (called the SAMI cycle framework later), which illustrates how science works in society
2. re-define entrepreneurship in the NOS context
3. designs and implements two pre-service science teacher education (PSTE) programmes on the previously mentioned three concepts (EOS, Entrepreneurship and the proposed framework - SAMI cycle framework). One of these programmes was on a continuous basis while the second was a once-off two hour workshop.
4. examines how pre-service science teachers’ (PSTs) understanding of these three concepts has been influenced by the research intervention
5. investigates PSTs’ educational views on the inclusion of these three concepts into the JCSS
6. scrutinises PSTs’ experiences during the first and second interventions (continuous and once-off PSTE) to contribute to teacher education
The significance of the current study is presented, and the rationale for the current study is discussed in the next section.

1.2. SIGNIFICANCE OF AND RATIONALE FOR THE CURRENT STUDY

This section presents the significance of NOS, EOS and entrepreneurship. Furthermore, the rationale for conducting the current study is discussed throughout the section. Each sub-section starts with the importance of the concept in science education, then moves to the importance of the concept in the curriculum, particularly in the JCSS in Ireland and concludes by presenting the potential benefits of the concepts to teachers, pre-service teachers and students.

1.2.1. Nature of Science

This section looks at the significance of and the rationale for investigating NOS in science education. Nature of Science (NOS) aims to explore how science and scientists work (Erduran and Dagher 2014a; Irzik and Nola 2014) and incorporates a range of cognitive, epistemic, social, political, historical, and economic perspectives into science education. NOS supports learning about science as well as the content of science. NOS is explained further in Chapter Two. According to Clough (2011), teaching NOS is of importance because it promotes interest and engagement in science classes and science careers, appreciation of science and the understanding of the strengths and limitations of science. Furthermore, NOS is also of importance due to its benefits to science education. For example, learning about science as well as the context of science can provide students with a deeper understanding of (1) the operation of science, (2) the production, validation and communication of knowledge and (3) the aims and values that science has (Martins and Ryder 2015). Likewise, according to Driver et al. (1996), applying NOS in science education can help students to have a better understanding of the process of science and to appreciate science as part of contemporary culture. Thus, NOS has benefits for and is important in science education.

By looking at NOS in the science education literature, the majority of studies conducted on NOS focus on the characterisation of NOS (Allchin 2014; Erduran
and Dagher 2014a; Irzik and Nola 2014; Lederman et al. 2002; Matthews 2012; McComas 1998), students and teachers’ perceptions of NOS (Khishfe 2017; Lederman 1992, 1999) and assessment of NOS (Erduran 2018; Erduran and Dagher 2014a; Lederman et al. 2014). These studies refer to the social aspects of NOS, such as social and cultural embeddedness and social-institutional system of science. For example, Erduran and Dagher (2014a) referred to the social aspects of NOS explicitly, such as social values and financial systems of science, and explained the benefits and importance of social aspects of NOS for science education, as evident in the direct quote below:

- Students may benefit from acquiring the social aspects of scientific communities, and the inclusion of social features of science in the classroom may facilitate students’ learning of science.
- Understanding science in its entirety will suggest that students learn about the social norms that scientists work by.
- Without the inclusion of the social context of science in science education, students are bound to have a limited understanding of how the scientific enterprise works, and how social structures, relationships and issues influence the development of science.
- Raising awareness of various aspects of science, whether they have had a positive or negative impact on society, is important for promoting understanding of science in a way that is consistent with its historical and contemporary practices.
- Engaging students in social aspects of science (e.g. discussion of colonial oppression through science) promotes ethical awareness and understanding so that oppression and destruction are avoided or at least minimised in future generations.

(Erduran and Dagher 2014a, pp.137-138)

By looking at NOS from the curriculum perspective, many countries have started to include NOS as part of the science curriculum (e.g. Ireland, the USA). The junior cycle science specification (JCSS) in Ireland1 focuses on the development of students’ knowledge of and about science through the unifying strand, NOS, and the four contextual strands: Physical World, Chemical World, Biological World, and Earth and Space. NOS is interwoven throughout these contextual strands in the JCSS. Therefore, NOS is also of importance in the science curriculum context due to its role in the JCSS as a unifying strand, which permeates all the strands of the specification. In the JCSS, “Science in Society” is one of the elements of the NOS

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1 Please see Appendix 1 for the place of Junior Cycle in Irish Education System.
strand, which reflects the social aspects of NOS. The targeted learning outcomes in “Science and Society” are:

1. Students should be able to research and present information on the contribution that scientists make to scientific discovery and invention, and its impact on society.
2. Students should be able to appreciate the role of science in society; and its personal, social and global importance; and how society influences scientific research.

(Department of Education and Skills (DES) 2015, p.16)

How science and scientists work in society is included within the scope of NOS in the learning outcomes in the JCSS. Even though the social aspects of NOS are important and beneficial for science education, and they are already involved in the JCSS, the social aspects of NOS and its classroom applications are also understudied (Allchin 2011; Jiménez-Aleixandre 2015; Peters-Burton 2012). For example, Peters-Burton (2012) found that pre-service teachers believe that social aspects of NOS were the least connected to the other NOS aspects. Furthermore, after an extensive search of the literature, no study emerged explaining and illustrating how science works in society, thus implying that there are no educational applications of it currently. Nonetheless, since NOS is in the curriculum, teachers need to have an understanding of how science works in society and the social aspects of NOS in order to teach them. Therefore, the integration of social aspects of NOS into teacher education is of importance to ensure that they can teach these concepts effectively. The role of NOS is also mentioned in the junior cycle context in Section 1.2.4 and teacher education context in Section 1.2.5. Thus, there is a gap in the science education literature on the social aspects of NOS and its educational applications.

Overall, there is a need to conduct research on the inclusion of social aspects of science and how science works in society into PSTE due to:

1. its mentioned benefits to science education, such as increasing students engagement in science (Clough 2011)
2. the importance of the social aspects of NOS in science education e.g. to promote ethical awareness (Erduran and Dagher 2014a)
3. the gap in the literature on the social aspects of NOS in PSTE.
The importance and benefits of NOS for science education is further explored in Chapter Two.

1.2.2. Economics of Science

This section looks at the significance of and rationale for investigating economics of science (EOS) in NOS and science education. EOS deals with the efficiency and inefficiency of scientific institutions and aims to understand the behaviour of scientists and the impact of science on the development of technology (Diamond 2008, p.1). In the last few decades, numerous studies have been conducted focusing on different aspects of EOS in science education, such as commercialisation of science (Irzik 2007, 2013), funding (Allchin 2011; Erduran and Dagher 2014a), and the interactions of EOS and science education (Erduran and Mugaloglu 2013). These studies highlighted the importance of the perspectives from EOS in science education. For example, Erduran and Mugaloglu (2013) emphasised the importance of the economic perspective in science education by advocating that the articulation of the economics that drive, shape, hinder or enable scientific inquiry would be considered as part of the scientific literacy.

Furthermore, Kelly (2007) stated that improving the awareness of students on current issues such as social and economic issues in science education can have a high impact on the economic well-being of a nation. Likewise, EOS empowers the university-industry relationship, the capitalisation of knowledge and economic and social development (Irzik 2007, 2013; Mirowski and Sent 2008). Driver et al. (1996) also addressed the importance of contemporary science, including the methods of funding and the systems of recognition and reward, which are within the scope of EOS. They also mentioned that teaching students how funding and grants affect the operation of science is significant. The importance and benefits of EOS in science education is further discussed in Chapter Two.

Even though EOS is not included in NOS explicitly, there are studies referring to the economic aspect of NOS. The majority of studies conducted on the economic perspective of NOS only focus on funding and financial systems of science in science education (Allchin 2011, 2014; Erduran and Dagher 2014a; Lederman et al. 2002). For example, Erduran and Dagher (2014a) referred to the “financial
“systems” in NOS. Moreover, these researchers emphasised the significance of teaching the economic aspect of science in NOS for science education (Alchini et al. 2014; Erduran and Dagher 2014a; Irzik and Nola 2014; Lederman et al. 2002). Erduran and Dagher (2014a) advocated that the inclusion of economic perspectives in NOS for science education would support students to develop finance-related skills, the awareness of socio-economic issues and appreciation of how some of their taxes are used for funding in scientific research.

From a broader perspective, teaching and learning about the economic aspect of science can (1) provide students and teachers with a greater understanding of the cross-curricular links relating to science, (2) make science more relatable to students’ everyday life and (3) aid students to realise the everyday applications of science (Kaya et al. 2018b). The benefit of promoting ethical awareness by engaging students in social aspects of science was mentioned within the NOS context. The inclusion of an ethical perspective to science could improve students’ perspective (Krimsky 2004; Irzik 2007, 2013; Resnik and Elliott 2013; Van Norman and Eisenkot 2017a, 2017b). Additionally, learning about the relationship between science and industry can increase job possibilities (Etzkowitz 2008; Stephan 1996). Therefore, the inclusion of EOS into NOS can provide broader benefits than economic benefits. EOS is important to people whether they work or study at primary, second or third level education due to (1) improving different skills, such as finance-related and critical thinking skills (Erduran and Mugaloglu 2013), (2) providing ethical awareness (Irzik 2007, 2013), (3) providing a more holistic understanding of the subject (Erduran and Dagher 2014a) and (4) increasing job opportunities (Etzkowitz 2008).

By looking at the economic perspective in NOS from the curriculum perspective, the economic aspect of science is emphasised within the learning outcomes of science education in different counties such as Turkey, the USA and Ireland (Board of Education and Discipline 2013). Investigating the economic aspect of NOS is also of importance in the curriculum context in Ireland since NOS is the unifying strand of the JCSS. According to a national document published by the DES (2016), economics is one of the future national skills in Ireland, which will be required in all levels of education by 2025. Additionally, one of the Statements of Learning (SOL) and its relevant learning in the JCSS are presented in Table 1.1.
Table 1.1 Links between junior cycle science and the statements of learning

<table>
<thead>
<tr>
<th>The statement</th>
<th>Examples of relevant learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOL 9. The student understands the origins and impacts of social, economic, and environmental aspects of the world around her/him.</td>
<td>Students will collect and examine data to make appraisals about ideas, solutions or methods by which humans can successfully conserve ecological biodiversity.</td>
</tr>
</tbody>
</table>

Source: DES (2015, p.6)

As seen in the link presented in Table 1.1, although the SOL targets economic perspective, the example of relevant learning in the JCSS does not explicitly refer to the economic aspect of science. Furthermore, even though the economic aspect of NOS is important and beneficial for science education, and it is already included in the JCSS, the role of EOS in NOS is not explored explicitly. Besides, according to Erduran and Mugaloglu (2013), existing science education literature pertaining to economic perspectives are not well informed by the formal discipline of EOS. Furthermore, since there is a reference to the economic aspects of the world in the JCSS, teachers should be able to refer to the economic aspect of NOS in the classroom. In this sense, teacher education is important to make teachers feel knowledgeable about the topic. EOS in teacher education is discussed further later in this chapter. After an extensive search of the literature, no study emerged on the role of EOS in NOS. Therefore, there is a gap in the literature on the role of EOS in NOS for science education and also in the availability of educational applications on the topic, both of which the current study aims to fill.

Overall, there is a need to conduct research on the inclusion of EOS into social aspects of NOS in PSTE due to:

1. the role and significance of EOS in NOS and science education
2. the benefits of a broader economic perspective of NOS in science education such as making science more relatable to students’ everyday life (Kaya et al. 2018b)
3. the link between the JCSS and SOL as presented in Table 1.1.
4. a gap in the research literature on the role of EOS in NOS and its educational applications in PSTE.
The importance and benefits of EOS for science education is further explored in Chapter Two and Chapter Three.

1.2.3. Entrepreneurship

This section looks at the significance of and the rationale for investigating entrepreneurship in NOS and science education. Different trends, such as environmental sustainability, inequality, globalisation, politics and technological change, determine the employability and the requirements in education and shape the future (Bakhshi et al. 2017). These trends also affect the required skills for employability. For example, in Ireland, Innovation 2020 and Enterprise 2025 aim to build a new economy based on enterprise and delivering sustainable employment. The Soft Skills For Business Success Report reflects on the Commonwealth Scientific and Industrial Research Organisation’s (CSIRO) hiring strategy and presents that CSIRO is looking for people who have soft skills, such as self-management, teamwork, problem-solving and innovation (Deloitte Access Economics 2017). Many research centres and programmes invested a tremendous amount of money to increase entrepreneurship and entrepreneurial activities worldwide. For example, Horizon 2020, which is the biggest EU research and innovation programme, invested billions of euros in taking ideas from the lab to the market, which relates to entrepreneurship. By doing so, this programme aims to support more breakthroughs, discoveries and world-firsts.

Due to the national and global changes, the targeted skills for the future are also changing in education. For example, Anderson et al. (2017) highlighted that what may have worked for schooling in the past is not always effectively working anymore and asserted the requirement for entrepreneurial learning in schools. Aligned with this, the Future Skills Report indicates that Business and Financial Operations Occupations in the US major occupation embrace Science as a complementary feature (Bakhshi et al. 2017). Thus, having EOS and entrepreneurship embedded within the science curriculum can facilitate meeting these requirements of the employers. Likewise, Etzkowitz (2008) claims that entrepreneurial training should be a part of general education since new

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2 Innovation 2020 is Ireland’s five-year strategy for research and development (R&D), science and technology.

3 Enterprise 2025 represents the government’s overall jobs strategy in Ireland.
organisation formations are becoming common in all parts of our lives. There are universities, such as Massachusetts Institute of Technology, University of Cambridge and Stanford University, that realise the importance of the integration of EOS and entrepreneurship to their education programme to transcend the development of significant research strengths (Etzkowitz 2008; Volkmann et al. 2009).

Therefore, teaching entrepreneurship within sciences from an early age is suggested rather than having to wait until students are older or at the university (for those that do progress to the third level). According to Volkmann et al. (2009):

> for today’s young people to realize their full potential, their 21st Century skill set must include unique proficiencies that will prepare them for the challenges of higher education and career development.

(Volkmann et al. 2009, p.116)

They recommend today’s young people to improve (1) themselves on core subjects of science, technology, engineering and math (also known as STEM), (2) learning skills, such as critical thinking and problem solving and (3) life skills, such as leadership and citizenship.

Three themes emerged from the science education literature relating to entrepreneurship. These are:

- the perspectives of PSTs and in-service science teachers on entrepreneurship (Amos and Onifade 2013; Bacanak 2013; Deveci 2016; Deveci and Seikkula-Leino 2016)
- the need for teaching entrepreneurship in science education (Achor and Wilfred-Bonse 2013; Deveci and Cepni 2014; Ejilibe 2012; Nwakaego and Kabiru 2015)
Furthermore, there are also projects conducted on entrepreneurship in science education showing that schools are no longer traditional in their approach (Anderson et al. 2017). For example, the Entrepreneurial School Project has been conducted in cooperation with different countries during 2014 and 2015 and emphasised the importance of entrepreneurship in and its contribution to education (The Entrepreneurial School (TES) 2014-2015). The Entrepreneurial School Project also shows how schools adopt innovative teaching methods, which leads to a more rounded student profile. This outcome is also similar to the findings of the Entrepreneurial Learning in Schools Report (Anderson et al. 2017). Overall, there is a need for industry-ready graduates (Birdthistle et al. 2007) and “the quality of workforce - a nation of people armed with relevant knowledge, entrepreneurial agility and analytical skills” (DES 2016, p.69). Therefore, the need for and importance of the inclusion of entrepreneurship in science education is evident in the literature.

Even though entrepreneurship is not explicitly referenced in the NOS literature, there are studies referring to science as an enterprise in the context of NOS (Erduran and Dagher 2014a; Irzik and Nola 2014). However, there is no evidence of research exploring the relevance and role of entrepreneurship to NOS by drawing the literature from the formal discipline of entrepreneurship. Although no evidence of this could be found, there are various benefits to include entrepreneurship in science education; for example, (1) providing students with self-employment as a career opportunity (Achor and Wilfred-Bonse 2013; Birdthistle et al. 2007; Bruyat and Julien 2001), (2) increasing students’ awareness on economics-related issues (Deveci 2016), (3) contributing to the social and economic development of a country (Amos and Onifade 2013), (4) creating industry-ready graduates to satisfy the need in the global world (Hynes et al. 2010), (5) a greater understanding of cross-curricular links of science (Kaya et al. 2018b), and (6) make students realise the everyday applications of science (ibid). Entrepreneurship can develop critical-thinking, decision-making, risk-taking and problem solving, creativity and innovation skills (Hisrich and Peters 2002). Further benefits and importance of the inclusion of entrepreneurship in science education are discussed in Chapter Two and Chapter Three.
By looking at entrepreneurship in NOS from the curriculum perspective, the European Commission (2012a) conducted research to develop national strategies for curricular implications of entrepreneurship education, including learning outcomes on entrepreneurship education in schools throughout Europe. There are also other counties that have included entrepreneurship in their science curriculum. For example, entrepreneurship is presented as one of the life skills in Turkey (Board of Education and Discipline 2013).

Within Ireland, the DES (2016) launched a national skills strategy up until 2025 and emphasised the importance of entrepreneurship as one of the targeted future national skills at all levels of education. In the strategy, the core (transversal) skills are identified as “creativity, innovation and entrepreneurship, critical & analytical thinking, teamwork, communication and business acumen” (ibid, p. 33). Statement of Learning (SOL) 22 in the junior cycle states that “the student takes the initiative, is innovative and develops entrepreneurial skills” (DES 2012, p.6). Therefore, entrepreneurship is also important in the curriculum context, particularly in the context of the JCSS. Even though entrepreneurship in NOS is important and beneficial for science education, and it is already involved in the JCSS, the role of entrepreneurship in NOS is not explored within the JCSS. Since there is a reference to entrepreneurship in the SOL in the curriculum, teachers should be able to refer to entrepreneurship in NOS. Therefore, having entrepreneurship as part of teacher education is essential to ensure teachers have an understanding about it (Amos and Onifade 2013; Lepisto and Ronkko 2013). Entrepreneurship is discussed in teacher education context in Section 1.2.5. Since after an extensive search, no research discussing the role of entrepreneurship in NOS could be found, thus implying that there is a gap in the current science education literature as well as a lack of related educational applications. Therefore, there is a gap in the literature on the role of entrepreneurship in NOS for science education and its educational applications, which the current study aims to fill.

Overall, there is a need to conduct research on the relevance and inclusion of entrepreneurship in NOS in PSTE due to:

1. the role and significance of entrepreneurship in NOS and science education (Deveci and Cepni 2014; Kaya et al. 2018b)
2. the benefits of entrepreneurship in NOS and science education such as providing students with self-employment as a career opportunity (Achor and Wilfred-Bonse 2013; Birdthistle et al. 2007; Bruyat and Julien 2001)
3. the link with the JCSS and SOL (DES 2015)
4. the gap on the role of entrepreneurship in NOS and its educational applications in PSTE.

This inclusion can be achieved through informing the NOS and science education literature from the formal discipline of entrepreneurship, which the current study aims to investigate.

1.2.4. Setting the Context of the Study

This section outlines second-level education in Ireland and refers to the changes in the Junior Cycle in Ireland and dominance of the assessment in Irish Education System. Second-level education in Ireland comprises two stages; Junior Cycle and Senior Cycle (See Appendix 1). Junior Cycle takes three years and it is typically for the students from age 12 to 15. At the end of third year, students sit a centrally mandated national stake exam called Junior Certificate examination. Senior Cycle takes two years and it is typically for the students with the age from 16 to 18. Likewise, at the end of the second year, students sit another national stake exam called Leaving Certificate examination (DES 2015).

Recently, many changes are occurring in the curriculum in Ireland. For example, NOS was included in the Junior Cycle curriculum as a unifying strand in 2015, which permeates all the strands of the curriculum, and the word “curriculum” changed to “specification” as in Junior Cycle Science Specification (JCSS). Furthermore, Irish Education System is going through some changes on assessment because of the changes in the curriculum and the issues regarding the national stake exams. Since assessment is an extensive topic itself and the focus of this thesis is not the assessment, issues of the assessment in Irish Education System is briefly outlined here.

The state examination dominates teaching, learning and assessment influencing different aspects of education, such as pedagogy, student-teacher relationships,
resources, time allocations and approaches to assessment in schools (McCormack 2010). Teachers have limited time for science teaching and exam preparation, and therefore they might not be willing to allocate their time to teach a concept out of the national state assessment. Even if the teachers try to allocate their time, “students find ways to cut corners – as some teachers do” (Eisner 2004, p.300). That is, assessment, particularly high stakes assessment can influence both teaching approaches and content selection (Lange and Meaney 2012) and influences what teachers, and students, do in the classroom. Therefore, it can be anticipated that unless these concepts form part of the national assessment, it is unlikely that teachers will be willing to teach them in the classrooms due to the domination of the pressure of catching up with the curriculum and fulfilling the assessment requirements.

The dominant and centralised role of assessment in teaching and learning, in particular the impact of the Leaving Certificate examination on students and teachers in Ireland, is also addressed in the literature (e.g. Jeffers 2011). Assessment, being the “tail that wags the curriculum dog” (Hargreaves 1989, cited in Barnes et al. 2000, p.624), can influence both teaching approaches and content selection. According to Lange and Meaney (2012), “assessment, especially high stakes assessment, becomes the de facto curriculum for teachers”. Consequently, while students started to target getting high score and meeting the examiners expectations, teachers started to perceive teaching to the examination results and an focusing on the attainment of results as the most important aspect of education (Government of Ireland 1998; McCormack 2010). Therefore, it may be a challenge to teachers to stop focusing on knowledge and teaching towards the exam and to move away from the prescribed curriculum (McCormack and O’Flaherty 2010). Due to the important role of teachers and teacher education, the next section focuses on teacher education.

1.2.5. Teacher Education

This section looks at the significance of and the rationale for conducting the current study with pre-service science teachers (PSTs) in the context of teacher education.

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4 Leaving Certificate examination is the final examination that students take at the end of their final year of second-level schooling, and it can determine their future study and career prospects.
Within this context, the teacher education system is highlighted, and the importance of and approaches to teacher education are discussed as well as the relevance of EOS, entrepreneurship and NOS to teacher education. Teacher education is mainly concerned with equipping teachers with knowledge, skills and attitudes (European Commission 2008, 2012a) to perform their role in the classroom, school and community efficiently based on contemporary policies, procedures and provision. Furthermore, how teachers are educated is significant to the sustainable economic growth and prosperity of countries (DES 2012).

There is a plethora of research highlighting the importance of teacher education (Conway et al. 2009; Darling-Hammond 2000a, 2000b, 2016). Aligned with this, according to a review of the pre-service teacher education in Australia:

> ensuring high quality teacher education is a first and critical step in delivering high quality teaching in schools, particularly in a time when the role of teachers is becoming increasingly complex and demanding.

(House of Representatives Standing Committee on Education and Vocational Training 2007, xxi)

Therefore, teacher education is highly important, and pre-service teacher education is fundamental to determine teachers’ future perspectives/roles.

Furthermore, teacher education is important in the current study due to the changes occurring in the curriculum in Ireland. Once the change is implemented, as in the JCSS, teachers need to be informed and educated about these changes to (1) engage in the new JCSS, (2) have an understanding of NOS and its aspects, and (3) support the changes in the curriculum, such as the inclusion of NOS and its social aspects, as evident in the recent changes implemented by the National Council for Curriculum and Assessment (NCCA) (DES 2015; NCCA 2015). These requirements can be achieved by providing effective pre-service teacher education and in-service teacher development. The current study focuses on the pre-service teacher education programmes because in these programmes, pre-service teachers start comprehending what it means to be a teacher and it may be difficult to change what they know once they start teaching at schools. Further research needs to explore and revisit emerging issues throughout teachers’ career (Lynch et al. 2017).
There is a requirement for a “fresh look” in teacher education due to social, cultural, economic and demographic changes in Ireland, targeting creativity and entrepreneurship, the impact of globalisation and the emerging knowledge society (Conway et al. 2009). Furthermore, a revision in teacher education is also required so that pre-service teachers keep up with developments and they are equipped to teach effectively in the classroom (Lambe and Bones 2006; Teaching Council of Ireland 2011). In this sense, PSTs should implement NOS into science classes due to the new framework being included into the JCSS. To implement NOS fully, PSTs need adequate pedagogical and content knowledge of social aspects of NOS, which includes EOS and entrepreneurship. Increasing PSTs’ pedagogical and content knowledge on such social aspects of NOS also benefits teacher education. For example, Erduran and Mugaloglu (2013) were of the opinion that the articulation of economic issues would benefit teacher education, and they stated that:

contemporary science teacher education initiatives would benefit from the articulation of such issues in order to inform teachers’ awareness and skills in teaching science in its economic context.

(Erduran and Mugaloglu 2013, p. 2421)

Learning about entrepreneurship can support a creative and innovative teaching environment due to the place of creativity and innovation in entrepreneurship (Burguer-Helmchen 2012; Hisrich and Peters 2002; Peverelli and Song 2012). Likewise, learning about EOS can increase teachers’ knowledge and awareness of developing low-priced teaching materials and obtaining funding to contribute to the school environment. Therefore, the social aspects of NOS, such as EOS and entrepreneurship, are significant in teacher education, and the teachers and teacher education play a vital role in the process of the change.

Teachers and teacher education have an important role in the process of the change. Moreover, the context of the current study is PSTs in Ireland. Therefore, teacher education in Ireland is explained in this paragraph. There are three levels in the Irish education system; the primary-level, second-level and the third-level. The third-level education involves some certificate/diploma courses, bachelor’s degree, master’s degree and PhD (philosophy of doctorate) degree. The context of the current study is third-level education, in particular, teacher education. There are

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5 Please see Appendix 1 for further details in the Irish Education System.
two programmes of pre-service teacher education available in Ireland: the concurrent and the consecutive programmes. The concurrent programme, which is the focus of the current study, allows pre-service teachers to study education-specific components and the school placement while studying their chosen academic discipline. Most students progress directly from a post-primary school and study a four-year degree that qualifies them to teach their chosen subject at the second level (McGarr and McCormack 2016). Many studies discuss effective approaches to teacher development, some of which are now explored.

1.2.5.1. Approaches to Teacher Education

According to the Organisation for Economic Co-operation and Development (OECD), an effective teacher education is:

ongoing, includes training, practice and feedback, and provides adequate time and follow-up support. Successful programmes involve teachers in learning activities that are similar to ones they will use with their students, and encourage the development of teachers’ learning communities.

(OECD 2009, p.49)

The evidence shows that effective approaches to teacher development engage (pre-service) teachers over an extended period of time (Broggy et al. 2015; Garet et al. 2001; Mayock et al. 2007; McCormack 2010; Opfer and Pedder 2010). These studies emphasise the importance of being exposed to a topic over an extended timeframe. Such an approach tends to result in greater levels of teacher understanding. Garet et al. (2001), for example, argue that there is a need for a continuous and intensive approach to teacher development, where teachers are exposed to different experiences of a topic over an extended period. This is supported by the work of Broggy et al. (2015), who involved PSTs in both a continuous and once-off form of professional development. They found that PSTs who were involved in the continuous teacher development showed more effective change. Broggy et al. (2015) identified the continuous involvement as attending a number of meetings while the once-off involved a three-hour workshop. Furthermore, Burquel and van Vught (2010, p.250) defined the once-off involvement in an activity as acquiring a snapshot of a given area on a once-off basis, and the on-going involvement in an activity as the process of acquiring new
strategic developments by “measuring and increasing organisational performance” in more than one involvement.

While continuous engagement in teacher development is ideal, some studies found positive outcomes of once-off involvement (Broggy et al. 2015; Garet et al. 2001). For example, the previously mentioned research conducted by Broggy et al. (2015), found positive outcomes of PSTs’ once-off involvement. However, concerns were raised regarding the ability of once-off involvement to sufficiently enhance teacher understanding (Mayock et al. 2007; McCormack 2010). Pre-service teacher education in Ireland is busy with a number of different agendas and topics vying for position. Engaging in a topic over an extended period of time may not always be feasible (Lynch et al. 2017). In this case, the once-off involvement may be needed at times and has also shown to have an impact (Broggy et al. 2015).

The current study engages pre-service teachers in professional development on both a continuous and once-off basis. Based on the studies and their definitions of the continuous and once-off involvement (Broggy et al. 2015; Burquel and van Vught 2010), the continuous PSTE in the current study was defined as the involvement of learners in an ongoing teaching process of applying different activities to develop an understanding of the given topic. The ongoing process was determined as six weeks in the current study. The once-off PSTE was determined as the involvement of learners in a teaching process once by applying one or more activities providing a snapshot of a given area to develop an understanding of the given topic.

1.2.5.2. Research on the Pre-service Teachers’ Understanding of Social Aspects of NOS

This section explores how PSTs’ “understanding” of a concept can be examined, particularly in relation to NOS. There are numerous studies in teacher education literature investigating pre-service teachers’ understanding of NOS in science education (Abd-El-Khalick and Lederman 2000; Akgun et al. 2017; Aksoz et al. 2017; Lederman 1992; Lederman et al. 2002; Mugaloglu et al. 2017; Peters-Burton 2012). The majority of these studies investigate the cognitive and epistemic aspects of NOS, such as scientific practices. For instance, Aksoz et al. (2017) investigated
PSTs’ understanding of scientific practices and found that participating in the research, participants’ understanding of scientific practices improved. They presented this improvement with participants’ categorisation of scientific practices, explanation of each component, and the relationships between these components and scientific practices. In another study, Mugaloglu et al. (2017) explored PSTs’ perceptions of models as scientific practices. Their results showed that science teachers’ and students’ understanding of the close relationship between models and other features of scientific practices contribute to their understanding of scientific practices. Peters-Burton (2012) conducted research with pre-service and in-service teachers to model relationships among the aspects of NOS through the use of network analysis. She found that in-service teachers made more connections between the aspects of NOS to make sense of scientific discipline, and had tighter connections among the aspects of NOS than pre-service teachers. She indicated that making more connections among the aspects of NOS referred to a higher understanding of NOS.

Likewise, Akgun et al. (2017) conducted a study to determine the PSTs’ understanding of the aims and values of science and found that participants’ understanding improved after participating in an intervention. They presented this improvement with the terminology used by participants concerning the aims and values of science. For example, while participants viewed the aims and values of science as “serving humanity, and understanding the universe and ethical issues” before the intervention, they focused on epistemic, cognitive and social aspects of science, objectivity, accuracy, honesty and exclusion of prejudice and bias” after the intervention (Akgun et al. 2017, p.2). They were examining the understanding of PSTs by determining PSTs’ use of relevant terminology.

Drawing on the above, the current study examines PSTs’ understanding of NOS, EOS and entrepreneurship by exploring a) how PSTs define these concepts, b) the relationships and connections PSTs make between these different concepts, and c) the relevant terminology PSTs use when talking about these concepts. These three areas are examined in both pre and post-interviews, hence identifying changes in PSTs understanding as a result of the intervention.
To summarise, the following gaps in the literature have been identified within this section:

- identifying the role of EOS in NOS (Erduran and Mugaloglu 2013)
- identifying the role of entrepreneurship in NOS (Achor and Wilfred-Bonse 2013)
- exploring and visualising how science works in society (Kaya et al. 2018a, 2018b)
- investigating PSTs’ understanding of EOS and entrepreneurship in NOS
- investigating PSTs’ perspectives on the inclusion of EOS and entrepreneurship into the JCSS.
- developing classroom activities on EOS and entrepreneurship in NOS (Achor and Wilfred-Bonse 2013; Deveci 2016)
- extending and developing classroom activities on the social aspects of NOS (Alchin 2011; Jiménez-Aleixandre 2015; Peters-Burton 2012)

Therefore, the current study contributes to the science education literature by:

1. exploring the role of EOS and entrepreneurship in NOS
2. re-defining entrepreneurship in the NOS context
3. visualising and explaining how science works in society
4. identifying PSTs’ understanding of EOS and entrepreneurship in the context of social aspects of NOS and the JCSS
5. determining PSTs’ understanding of how science works in society in the context of NOS and the JCSS.
6. developing and performing some activities to improve PSTs’ understanding of social aspects of NOS

1.3. THESIS STRUCTURE

The current study is comprised of three parts. PART ONE, “Introduction and Literature Review”, is concerned with the theoretical aspects of the research topic and includes three chapters. This chapter - Chapter One - identified the purpose and objectives of the current study, presented the background to set the scene of the study, discussed the significance of the study and identified the rationale for the
study as well as acting as a guide to the current study. Chapter Two gives a comprehensive review of the literature on NOS, EOS and entrepreneurship. Based on the literature review, entrepreneurship is re-defined in the context of NOS. Furthermore, the aspects of EOS and entrepreneurship are identified based on the literature review conducted in Chapter Two. Presenting the characteristics of NOS and systematically categorising EOS and entrepreneurship lead the way to reconceptualise the “financial systems” and conceptualise how science works in society in the following chapter. Thus, Chapter Three argues the emerging issues in the “financial systems” in NOS and proposes “contemporary social aspects of NOS” as an alternative way to overcome the issues that “financial systems” have. Within this context, the relationship between NOS, EOS and entrepreneurship is discussed, and EOS and entrepreneurship are involved in NOS as “contemporary social aspects of NOS”. Furthermore, EOS, entrepreneurship and NOS are conceptualised in a new framework to explain how science works in society. This framework is called the SAMI cycle framework which stands for the relationship between the State/government, Academia, Market and Industry. Therefore, PART ONE contributes to the science education literature through (1) exploring the role of EOS and entrepreneurship in NOS, (2) re-defining entrepreneurship in the NOS context, (3) proposing “contemporary social aspects of NOS” to promote a holistic and comprehensive understanding of NOS, and (4) visualising and explaining how science works in society.

PART TWO, “Methodology and Findings”, includes three chapters. Chapter Four identifies the aim, questions, paradigm and the methodology adopted for the current study. These decisions inform the research design, data collection and data analysis and the ethical stance of the current study. The continuous and once-off PSTE are introduced in the research design. Within the continuous and once-off PSTE, the development of the research instruments, the pilot research, the sampling and data collection techniques are identified and argued and the data analysis techniques are discussed. Finally, validity, reliability and ethical considerations of the current study are discussed. Chapter Five presents the research findings related to the contemporary social aspects of NOS, which are EOS and entrepreneurship. Within this context, PSTs’ understanding of the contemporary social aspects of NOS and their perspectives on the inclusion of these aspects into the JCSS are explored. Chapter Six presents the research findings related to the SAMI cycle.
framework. Within this context, PSTs’ understanding of the SAMI cycle framework and their perspectives on the inclusion of this framework into the JCSS is explored. The PSTs’ experiences of the current study are also explored in this chapter. Therefore, PART TWO contributes to the science education literature through its completion by (1) developing and performing some activities to improve PSTs’ understanding of social aspects of NOS, (2) identifying PSTs’ understanding of EOS and entrepreneurship in the context of social aspects of NOS, (3) determining PSTs’ educational views on the inclusion of EOS and entrepreneurship in the JCSS, (4) identifying PSTs’ understanding of how science works in society (the SAMI cycle framework) in the context of NOS, (5) determining PSTs’ educational views on the inclusion of the SAMI cycle framework in the JCSS, and (6) exploring the PSTs’ experiences of the continuous and once-off PSTE for a more effective and well-rounded education.

PART THREE is concerned with the discussion and conclusion of the research findings within the science education literature and includes two chapters. Chapter Seven is the discussion chapter. The research findings are discussed based on the impact of contemporary social aspects of NOS and the SAMI cycle framework on moving from fragmented understanding to holistic view of science, inclusion of these concepts in the JCSS based on their benefits and aspects (i.e. knowledge, understanding, skills and attitudes), and their implications for teacher education and science education. Chapter Eight concludes the current study based on the research questions and presents future directions and personal reflection of the researcher on the research process.
2 CHAPTER TWO: NOS, EOS AND ENTREPRENEURSHIP

The objective of this chapter is to review the literature on nature of science (NOS), economics of science (EOS) and entrepreneurship. Within this context, definitions and characterisation of NOS (different NOS approaches), aspects/scopes of EOS, and definitions and aspects of entrepreneurship are examined. Based on this, the NOS approach that is adopted in the current study is identified, and entrepreneurship is re-defined in the context of NOS. Additionally, the studies conducted on NOS, EOS and entrepreneurship are presented within the science education literature. Part of the current study carried out for this literature in Chapter Two has been published in Kaya, S., Erduran, S., Birdthistle, N. and McCormack, O. (2018) ‘Looking at the social aspects of nature of science in science education through a new lens: The role of economics and entrepreneurship’, Science & Education, 27(5), pp.457-478. All the analytical discussions conducted in Chapter Two set the scene for the current study to reveal the relationship between NOS, EOS and entrepreneurship, hence prepares the foundation for the arguments made in Chapter Three. This chapter starts with introducing and defining NOS and justifying the choice of the theoretical framework of the current study.

2.1. NATURE OF SCIENCE

This section aims to determine the importance of NOS and contemporary approaches characterising NOS. Moreover, this section presents the theoretical framework of the current study and the justification of this choice.

During the past few decades, research interest in interdisciplinary characterisation of science has become prominent in the science education literature. Here, interdisciplinary characterisation of science refers to the cross-curricular links between different domains, such as sociology and philosophy. Some of these interdisciplinary studies are “Socio-Scientific Issues” (e.g. Lee et al. 2012; Sadler and Dawson 2012), “Science-Technology-Society-Environment” (e.g. Pedretti and
Nazir 2011), “History and Philosophy of Science” (e.g. Matthews 2014) and “Nature of Science” (e.g. Erduran and Dagher 2014a; Lederman et al. 2002). The focus of the current study is on NOS in science education, in particular, the social aspects of NOS.

Many researchers from different fields such as sociology, history and philosophy attempted to understand NOS (Alters 1997; Ziman 2000). Education theorists and researchers often defined NOS as how science works (Allchin et al. 2014; Erduran and Dagher 2014a; Irzik and Nola 2014; Martins and Ryder 2015). For instance, according to Clough (2011), NOS is to understand what science is, how science and scientists work, what are the assumptions underlying the scientific knowledge, and how society influences and reacts to science. Martins and Ryder (2015) referred to NOS by emphasising learning about science, including how science works, rather than only learning the scientific knowledge. Within the context of learning about science, they stated that:

> a deeper understanding of how science works, how scientific knowledge is produced, validated and communicated, as well as the very nature of this knowledge, in regard to its epistemological particularities, has been seen as something to be sought and of value for science education.

(Martins and Ryder 2015, p.1)

A well-known development emphasising the importance of “learning about science” is the initiation of the National Science Foundation (NSF) at the beginning of the 1950s. By this development, one of the aims of the high school curriculum in the USA was defined as preparing future scientists by engaging students in thinking like scientists. Furthermore, by the end of the 1960s, Kimball (1968) propounded a model of NOS after an extensive review of the nature and philosophy of science literature. The primary statements of his model are summarised below:

1. The fundamental driving force in science is curiosity concerning the physical universe.
2. In the search for knowledge, science is process-oriented; it is a dynamic, ongoing activity rather than a static accumulation of information.
3. In dealing with knowledge as it is developed and manipulated, science aims at ever-increasing comprehensiveness and simplification.
4. There is no one “scientific method” as often described in school science textbooks.
5. The methods of science are characterised by a few attributes, which are more in the realm of values than techniques. Among these traits of science are dependence upon sense experience ... and of usefulness in furthering scientific inquiry.

6. A basic characteristic of science is a faith in the susceptibility of the physical universe to human ordering and understanding.

7. Science has a unique attribute of openness, both openness of mind, allowing willingness to change opinion in the face of evidence, and openness of the realm of investigation, not limited by such factors as religion, politics, or geography.

8. Tentativeness and uncertainty mark all of science. Nothing is ever completely proven in science, and recognition of this fact is a guiding consideration of the discipline.

(Kimball 1968, pp.111-112)

Particularly, the seventh statement of Kimball (1968) was referring to the social aspects of science. At the beginning of the 1990s, NOS was included in the science curriculum in the US in two national documents: National Science Education Standards by National Research Council (NRC 1996) and Benchmarks for Scientific Literacy by the American Association for the Advancement of Science (AAAS 1993). In Delphi Study, Osborne et al. (2003) sought to know whether there is support in the expert community for an account of NOS. As a result, they suggested that researchers should pay attention to the explicit teaching of NOS, its epistemic base and its cultural elements. Within an Irish context, it was only in 2015 that the JCSS started to focus on the development of students’ knowledge of and about science through NOS, and NOS was included in the JCSS as the unifying strand (DES 2015). As seen, many studies have been conducted throughout the years explaining what NOS is, characterising NOS and emphasising the importance of NOS.

Recently, there has been a collective agreement in the science education literature on teaching students NOS as well as the science content (DES 2015; NSTA 2003; Osborne et al. 2003). For example, according to Peters-Burton and Baynard (2013):

an understanding of how science is enacted and how scientific knowledge is generated, also known as the nature of science (NOS), is a major goal of science education.

(Peters-Burton and Baynard 2013, p.1)
This collective agreement may be because of the benefits of learning about NOS. Driver et al. (1996) identified the potential advantages of learning about NOS, such as understanding the scientific process and making informed decisions on socio-scientific issues. According to Clough (2011), teaching NOS is of importance because it promotes:

- appreciation of science
- an increased interest in science classes and science careers
- greater engagement in learning about biological evolution
- better understanding of science’s strengths and limitations, the role of science in social decision-making, and many science concepts

(Clough 2011, p.56)

Even though there is a major agreement on the importance and benefits of NOS, its characteristics are still contradictory. Education theorists and researchers have attempted to define NOS and gave a demarcation criterion to identify it (Allchin 2011; Erduran and Dagher 2014a; Irzik and Nola 2011; Matthews 2012). Thus, a variety of characterisations of NOS and several foundational studies attempting to characterise NOS in science education emerged (Abd-El-Khalick et al. 1998; Allchin 2011; Irzik and Nola 2011; Kimball 1968; Matthews 2012; McComas et al. 1998). The contemporary foundational NOS approaches are explored within this section.

Figure 2-1 was developed to summarise the contemporary NOS approaches including the components of the social-institutional system (SIS) of science in the extended Family Resemblance Approach (FRA). The colour red font illustrates the theoretical framework and its components that is utilised in the current study.
To comprehend the characteristics of NOS in the current study, different contemporary foundational NOS approaches in science education are introduced in the following section; consensus view, whole science, features of science (FOS) and family resemblance approach (FRA).
2.1.1. Contemporary Characterisation of Nature of Science in Science Education

This section introduces the different contemporary foundational NOS studies to show how understanding of NOS has evolved during the last few decades and identifies the characteristics of NOS highlighted in these approaches. This section also explores the role of EOS and entrepreneurship as one of the social aspects of NOS between these NOS approaches. The approaches of “consensus view”, “whole science”, “features of science” (FOS) and “family resemblance approach” (FRA) are now explored respectively.

2.1.1.1. Consensus View of the NOS

One of the contemporary foundational NOS approaches is known as the “consensus view”. Within this view, NOS referred to science as a way of knowing, the epistemology of science, and the values and beliefs inherent to the development of scientific knowledge (Lederman 1999). For example, Abd-El-Khalick et al. (1998) highlighted three central concepts emerging in their research, which were the empirical basis and tentativeness of science, subjectivity and creativity in science, and theoretical constructs in science. Likewise, McComas et al. (1998) extracted eight international science standard documents and detected 14 consensus views regarding NOS. The compacted and structured version of these views is presented in the seven tenets characterising the NOS (Lederman et al. 2002). These tenets are called “consensus view”:

1. Observation, influence and theoretical entities in science: Observations are descriptive statements about natural phenomena that are directly accessible to the senses (or extensions of the senses). By contrast, inferences are statements about phenomena that are not directly accessible to the senses.

2. Scientific theories and laws: Scientific theories are well-established, highly substantiated, internally consistent systems of explanations. Laws are descriptive statements of relationships among observable phenomena. Theories and laws are different kinds of knowledge and one does not become the other.

3. The creative and imaginative nature of scientific knowledge: Science is empirical. Nonetheless, generating scientific knowledge also involves human imagination and creativity.

4. The theory-laden nature of scientific knowledge: Scientific knowledge is theory-laden. Scientists’ theoretical and disciplinary commitments,
beliefs, prior knowledge, training, experiences, and expectations actually influence their work.

5. The social and cultural embeddedness of scientific knowledge: Science as a human enterprise is practiced in the context of a larger culture and its practitioners are the product of that culture.

6. Myth of scientific method: The myth of the scientific method is regularly manifested in the belief that there is a recipe-like stepwise procedure that all scientists follow when they do science. This notion was explicitly debunked.

7. The tentative nature of scientific knowledge: Scientific knowledge, although reliable and durable, is never absolute or certain. This knowledge, including facts, theories, and laws, is subject to change.

(Lederman et al. 2002, pp.500-502)

As mentioned previously, the focus of the current study is the social aspects of NOS. When the tenets of the consensus view are examined within this context, only the fifth tenet (The Social and Cultural Embeddedness of Scientific Knowledge) of the “consensus view” is relevant to the aim of the current study.

There have been some criticisms of the consensus view. For example, according to Allchin (2011), there is no profound explanation of these factors, notably, socio-economic factors. Other studies also criticised the consensus view:

- The philosophy behind the NOS is more than a list of tenets (Eflin et al. 1999).
- Consensus view oversimplifies the nature of observation and theory and also disregards the role of models in science (Grandy and Duschl 2007).
- Consensus view is a too narrow and monolithic picture of science, which means that it is blind to the aims of science, methodological rules and differences among scientific disciplines (Irzik and Nola 2011).
- Consensus view lacks sufficient systematic unity (ibid.).
- Giving a list of tenets to students is seen as something to be transmitted to students rather than to be explored. NOS is complex and varied; it is more than giving specific NOS ideas to students (Clough 2011).
- Many items regarding science as an enterprise, such as the role of funding, motivations, peer review, cognitive biases, fraud, and the validation of new methods, are absent in this view (Allchin 2011).
Some aspects of this view are unclear and/or problematic as well as being limited and simplified (Martins and Ryder 2015).

Concerning the aims of the current study, even though Lederman et al. (2002) refer to the social embeddedness, there is no extensive explanation and articulation of the statement. For example, they state that science affects and is affected by the various elements of culture, such as social fabric, politics and socio-economic factors. Additionally, there is no reference to entrepreneurship. Due to these criticisms, other contemporary NOS approaches emerged to reframe the characterisation of NOS. One of these approaches is the “whole science”.

2.1.1.2. Whole Science

Another contemporary foundational NOS approach is called “whole science”. This approach was introduced by Allchin (2011) who aimed to reframe:

current NOS characterisations from selective lists of tenets to the multiple dimensions shaping reliability in scientific practice, from the experimental to the social, namely to “Whole Science”.

(Allchin 2011, p.518)

Allchin (2011) criticised the consensus view as being incomplete and insufficient for functional scientific literacy. Therefore, he supported shifting from declarative statements to functional/interpretive analysis including “personal and social decision making”. Allchin (2011) stated that real-life situations should be used for classroom teaching, and the assessment should be authentic. By embracing the use of real-life situations for teaching, he aimed to strengthen the social aspects of science due to its omission in previous NOS approaches. For this reason, he offered a few prototypes for teaching NOS, a table on dimensions of reliability in science, some sample NOS questions and a sample assessment for reviewing NOS. The prototypes in his paper are the lesson activities produced based on real-life situations to teach NOS. The dimensions of reliability in scientific practices are to make students realise that scientific claims may fail and to inform students about how to prevent, mitigate, or accommodate potential errors in science.
There have been some criticisms proposed relating to the whole science. For example, Schwartz et al. (2012) criticised the “whole science” as being unfounded and inconsistent due to treating NOS as a skill and stated that:

the objectives Allchin targets are more aligned with inquiry and the nature of scientific inquiry (NOSI), rather than knowledge of NOS. We make a distinction between inquiry abilities, NOSI, and NOS in our work ... whereas Allchin lumps all these constructs together into “doing NOS”, thus minimising the importance of understanding these concepts, constructions and their associated nuances and interrelationships.

(Schwartz et al. 2012, p.686)

Regarding the aims of the current study, although Allchin (2011) claims that one of the 10 dimensions of reliability in science is “economics/funding” (i.e. eighth bullet-point within the ten dimensions), there is no example explicitly emphasising the economics or exemplifying the transformation of “economics/funding” into classroom practice in this approach. Although he stated that the “economics/funding” dimension of this approach includes sources of funding and personal conflict of interest, the explanation of the personal conflict of interest in this dimension is very limited. Therefore, in this approach, the reference to “economics/funding” in learning resources is minimal, and there is no reference to entrepreneurship. Thus, there is a need for an extension and clarification of enterprise and economic dimensions, its comprehensiveness and its implementation into science classes. Due to these criticisms, other contemporary NOS approaches criticising the “consensus view”, and the “whole science” also emerged to reframe the characterisation of NOS, such as the “features of science”.

2.1.1.3. Features of Science (FOS)

Matthews (2012) found whole science and consensus view inadequate and claimed that NOS elements should be refined philosophically and historically to be more beneficial for teachers and students. Moreover, by referring to the seven tenets of Lederman (2002), he stated that:

if they are features of science, then there is no good reason why just those seven features are picked out, and not others of the numerous features - epistemological, historical, psychological, social, technological, economic, etc. - that can be said to characterise scientific endeavour, … .

(Matthews 2012, p.18)
Based on this perspective, Matthews (2012) redefined NOS with a new list defining features of science. FOS focuses on the nature of scientific knowledge and examines the processes, institutions and cultural and social contexts in which the knowledge has been produced. The targeted features of science are as follows:

1. Empirical basis
2. Scientific theories and laws
3. Creativity
4. Theory-dependence
5. Cultural embeddedness
6. Scientific method
7. Tentativeness
8. Experimentation
9. Idealisation
10. Models
11. Values and Socio-scientific issues
12. Mathematisation
13. Technology
14. Explanation
15. Worldviews and Religion
16. Theory choice and rationality
17. Feminism
18. Realism and Constructivism

(Matthews 2012, pp.18-20)

By propounding the “features of science” (FOS), Matthews (2012) aimed to broaden the “consensus view” to make it less declarative and more adaptable for classroom teaching and learning. Matthews (2012) criticised the “consensus view” by not reasoning their selection of the seven statements and excluding other numerous features of science such as epistemological, historical, psychological, social, technological, and economic. Some studies also criticised the FOS. For example, Erduran and Dagher (2014a) criticised the organisational structure of this approach by stating that:

the FOS features he has proposed to resemble a disparate set of ideas some of which reflect epistemic aspects of science on the one hand (e.g. explanation, theory choice and rationality), while others reflect a philosophical stance (e.g.
Moreover, in FOS, the author does not justify his selection of these 18 features of science. Relating the aims of the current study, even though economics was highlighted as one of the missing features in NOS, it is not included as one of the features of science. Additionally, the importance of entrepreneurship and its relevant terminology are not mentioned. Due to these criticisms, Irzik and Nola (2011) also criticised the other NOS approaches by not being able to embrace all aspects of science without sacrificing its diversity and proposed the “family resemblance approach”.

2.1.1.4. Family Resemblance Approach (FRA)

The idea of family resemblance was developed by Wittgenstein (1958) and adapted from the philosophy of science to NOS in science education by Irzik and Nola (2011), who developed a more powerful, comprehensive and systematic alternative to the consensus view. They claimed that the “family resemblance approach” (FRA) embraces all aspects of science and supports the unity of science without sacrificing its diversity. The central premise in explaining the concept of family resemblance is that:

there are a few core characteristics that all the sciences share (data collection and inferences, for instance), but they are not sufficient either to define science or to demarcate it from other human endeavours.

(Irzik and Nola 2011, p.595)

Thus, Irzik and Nola (2011) suggested investigating dissimilarities as well as similarities of each science and building up a set of characteristics for each of them. Furthermore, they stated that science cannot be distinguished from social, cultural, historical and political factors. The FRA conceptualises science as a cognitive-epistemic and social system and promotes their interaction with each other. Even though Irzik and Nola did not mention “science as a social system” in 2011, they offered the inclusion of this system in 2014 (Irzik and Nola 2014). Table 2.1 summarises the conceptualisation of FRA by Irzik and Nola (2014) with its main categories constituting science.
Table 2.1: The eight categories of science in FRA

<table>
<thead>
<tr>
<th>Science as a Cognitive-Epistemic System</th>
<th>Science as a Social System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Processes of Inquiry</td>
<td>Professional Activities</td>
</tr>
<tr>
<td>Aims &amp; Values</td>
<td>Scientific Ethos</td>
</tr>
<tr>
<td>Methods &amp; Methodological Rules</td>
<td>Social</td>
</tr>
<tr>
<td>Scientific Knowledge</td>
<td>Certification of Scientific Knowledge</td>
</tr>
<tr>
<td></td>
<td>Dissemination of Scientific Knowledge</td>
</tr>
<tr>
<td></td>
<td>Social Values</td>
</tr>
</tbody>
</table>

Source: Irzik and Nola (2014, p.13)

The reason for the categorisation in Table 2.1 was explained as providing the conceptual clarity rather than causing categorical separation. Although there was no reference made to economics in FRA by Irzik and Nola (2011), in 2014 they stated that:

science is many things all at once: it is an investigative activity, a vocation, a culture, and an enterprise with an economic dimension … .

(Irzik and Nola 2014, p.8)

Furthermore, the commercialisation of science was referred to as one of the aspects of science (Irzik and Nola 2014). They mentioned that the reliability of knowledge is related to the social system of scientific knowledge production as well as scientific methods and methodological rules.

Irzik and Nola (2014) highlighted that:

students must understand that ethical norms like intellectual honesty and openness and social mechanisms of peer review, free and critical discussion are as important as processes of inquiry such as experimenting or in using methods, like the hypothetico-deductive method of testing, in producing reliable knowledge.

(Irzik and Nola 2014, p.1013)

They believed that this approach sufficiently covers the mentioned points, such as intellectual honesty and social mechanisms of peer-review, and this approach is a pedagogically useful approach for classroom practice. Erduran and Dagher (2014a)
analysed the different aspects of the other contemporary NOS approaches and developed Table 2.2 to summarise their analysis.

Table 2.2: Comparative overview of Nature of Science (NOS) consensus view, Features of Science (FOS) approach and the Family Resemblance Approach (FRA)

<table>
<thead>
<tr>
<th>NOS consensus view</th>
<th>Features of science approach</th>
<th>Family resemblance approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highlights cultural embeddedness</td>
<td>Includes: Values and socio-scientific issues</td>
<td>The expanded social context recognizes cultural embeddedness and societal and religious values</td>
</tr>
<tr>
<td></td>
<td>Worldviews and religion-values and socio-scientific issues</td>
<td></td>
</tr>
<tr>
<td>Includes Creativity</td>
<td>?</td>
<td>Creativity is a psychological component that characterizes aims and methods, practices, methods, and scientific knowledge. It is implicit in the FRA</td>
</tr>
<tr>
<td></td>
<td>Includes the following philosophical positions:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Realism</td>
<td>The FRA does not make a commitment to any of these positions. In this sense, it is philosophically neutral</td>
</tr>
<tr>
<td></td>
<td>Constructivism</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Feminism</td>
<td></td>
</tr>
<tr>
<td>Rationality Objectivity/Subjectivity</td>
<td>Lists: Theory choice and rationality which involve a set of aims and values</td>
<td>Includes scientific aims and values that subsume rationality and theory choice as an aim and value</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lists practices that include:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Experimentation</td>
<td>Includes nature of scientific practices pertaining to observation, experimentation, classification and so on</td>
</tr>
<tr>
<td></td>
<td>Idealization</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Technology</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Explanation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mathematization</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Focuses on the idea that scientists use many methods: no one scientific method</td>
<td>?</td>
<td>Methodologies and methodological rules</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distinguishes between: scientific theories and laws observations and inferences</td>
<td>Includes models</td>
<td>Scientific knowledge: Epistemological aspects of models, theories, laws and explanations and aspects pertaining to them such as knowledge revision</td>
</tr>
<tr>
<td>Focuses on tentativeness</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Erduran and Dagher (2014a, p.26)
As a result of their analysis presented in Table 2.2, Erduran and Dagher (2014a) were of the opinion that FRA is more comprehensive and informative than the other NOS approaches. Concerning the aims of the current study, commercialisation of science was referred to as one of the aspects of science by Irzik and Nola (2014), which is presented as one of the aspects of EOS in the current study. Nonetheless, there is no explanation or explicit inclusion of EOS, and there is no context about entrepreneurship in this approach. By identifying some missing aspects and educational implications of this approach, Erduran and Dagher (2014a) have extended and elaborated the previously conceptualised FRA by Irzik and Nola (2011, 2014). In the following section, the extended FRA is introduced as the theoretical framework of the current study and examined thoroughly.

2.1.2. The Extended Family Resemblance Approach

This section aims to introduce the extended FRA and its social aspects. Furthermore, this section justifies the reasons for determining “the extended FRA” as the theoretical framework of the current study. Erduran and Dagher (2014a) believed that NOS encapsulates broader perspectives, and FRA embraces the broader perspectives that have to be acknowledged when teaching science. For example, they were of the opinion that FRA contributes to improving the:

- respect for diversity and inclusion; care for motivation and affective dimensions of learning; and social justice in making science and scientific reasoning accessible.

(Erduran and Dagher 2014a, p.2)

Therefore, Erduran and Dagher (2014a) aimed to develop a more comprehensive and thorough FRA-based NOS account for science education. This approach was called “the extended FRA” (Erduran and Dagher 2014a). This approach is also called Reconceptualised FRA-to-NOS (RFN) to prevent the confusion between FRA and “the extended FRA”. This is further discussed in the paper written by Kaya and Erduran (2016). However, this approach is called “the extended FRA” in the current study since its first use in the literature is “the extended FRA”.

A primary distinction of the extended FRA and the FRA is that the extended FRA is pedagogically more informed and driven. In other words, while the FRA adopted by Irzik and Nola (2011; 2014) is more a philosophical account, the extended FRA adopted by Erduran and Dagher (2014a) is a pedagogical account based on the
philosophy of science literature. Furthermore, in the extended FRA (1) processes of inquiry in science as a cognitive epistemic system (See Table 2.1) was changed to scientific practices, (2) three more categories, namely social organisations and interactions, political power structures, and financial systems were added into the social system of science offered by Irzik and Nola (2014), and (3) the name of the system was changed from “science as a social system” to “science as a social-institutional system” to reconceptualise NOS holistically. Furthermore, the teaching and learning aspect of FRA was broad (Erduran and Dagher 2014a). Thus, educational applications of each component were also presented in the extended FRA to have a functional framework for instructional and learning purposes. Therefore, the extended FRA was characterised into 11 components in two systems which are the cognitive-epistemic and the social-institutional system. While the cognitive-epistemic system includes four components, the social-institutional system is comprised of seven components. These eleven components are presented in Table 2.3.

Table 2.3: The eleven categories of science in the extended FRA

<table>
<thead>
<tr>
<th>Science as a Cognitive-Epistemic System</th>
<th>Science as a Social-Institutional System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aims &amp; Values of Science</td>
<td>Scientific Practices</td>
</tr>
<tr>
<td>Scientific Practices</td>
<td>Scientific Ethos</td>
</tr>
<tr>
<td>Methods &amp; Methodological Rules</td>
<td>Social Certification and Dissemination</td>
</tr>
<tr>
<td>Scientific Knowledge</td>
<td>Social Values of Science</td>
</tr>
<tr>
<td></td>
<td>Social Organisations and Interactions</td>
</tr>
<tr>
<td></td>
<td>Political Power Structures</td>
</tr>
<tr>
<td></td>
<td>Financial Systems</td>
</tr>
<tr>
<td></td>
<td>Professional Activities</td>
</tr>
</tbody>
</table>

Erduran and Dagher (2014a) developed Figure 2-2 to show how the components of science as a cognitive-epistemic system interact with those of science as a social-institutional system.
Erduran and Dagher (2014a) explained how the FRA Wheel works by stating that:

science as a cognitive-epistemic system occupies a space divided into four quadrants that accommodate its four categories as discussed earlier. This circle floats within a larger concentric one … .

(Erduran and Dagher 2014a, p.28)

The larger concentric circle involves the components of the social-institutional system of science. As represented in Figure 2-2 and described by Erduran and Dagher (2014a), there is a relationship between all categories of the FRA. Due to the focus of this study, only the social-institutional system of science is introduced and explained in detail below. Seven components of this system are summarised in the next section based on Erduran and Dagher (2014a) and Kaya and Erduran (2016).
2.1.2.1. Science as a Social-Institutional System

This section introduces the social-institutional system (SIS) of science and explains the components of this system. Science is a social-institutional system (SIS) including the interaction of scientists with their working environments including groups, working materials, institutions, and organisations. Furthermore, this system involves how scientists exercise social values, activities and ethos throughout this interaction. Erduran and Dagher (2014a) demonstrated the seven components of the SIS of science and their categories in Figure 2-3.

![Figure 2-3: Science as a social-institutional system and its categories](source)

Source: Erduran and Dagher (2014a, p.151)

This system aims to illustrate the scientific enterprise in the social and institutional contexts. Erduran and Dagher (2014a) question the political, economic and sociologic factors that affect the scientific enterprise and the impact of these factors on scientists and scientific communities throughout the seven components of the
SIS of science. These seven components are briefly explained below based on Erduran and Dagher (2014a) and Kaya and Erduran (2016).

2.1.2.1.1. Professional Activities

This component emphasises that scientists not only conduct scientific investigations but also engage in professional activities. These professional activities include attending conferences, presenting and/or publishing research outcomes, writing research proposals, seeking funding and reviewing papers as well as grant applications (Irzik and Nola 2014). That is, professional networking, presenting, writing, financial understanding and critical thinking to evaluate others’ work relative to the standards of a community are also the skills required for being a scientist. This component shows that scientists are embedded in community practices such as public sharing and dissemination of results to certify and validate their findings. There are many activities for students, such as Olympiads, which can be adapted to education based on the professional activities that scientists perform. By inclusion of these activities, increasing students’ awareness of their acting, thinking and communicating ways in science is targeted.

2.1.2.1.2. Scientific Ethos

Scientific ethos involves ethics and scientists’ attitudes. According to Irzik and Nola (2014), scientific ethos includes:

attitudes that scientists are expected to adopt and display in their interactions with their fellow scientists as well as in carrying out their scientific activities.

(Irzik and Nola 2014, pp.1006-1007)

This component is to show that there are social norms and scientific ethos that scientists adopt when they are engaged in any scientific activities. It is also important to highlight that not following these social norms can result in sanctions. The social norms mentioned include the Mertonian and Resnik’s norms (Erduran and Dagher 2014a). Mertonian norms are universalism, organised scepticism, disinterestedness, and communalism. Universalism sustains that the validity of scientific claims is not affected by scientists’ personal factors/attributes such as nationality or religion. Organised scepticism involves conducting a critical analysis
of claims by using scientific reasoning. Disinterestedness refers to scientists’ independence from their personal preferences and acting for a common benefit. Communalism supports the common ownership of scientific knowledge and openness concerning the exchange of ideas and information rather than its secrecy. These four norms are useful for inquiry-based science teaching and students to comprehend how scientists formulate and evaluate valid claims. Resnik’s norms include intellectual honesty; respect for research subjects, environment, colleagues and intellectual property; freedom; openness; integrity; carefulness; confidentiality; responsible publication and mentoring; social responsibility; non-discrimination; competence; and legality. These cognitive and epistemic values are essential for students to realise the ethos and values that scientists adopt. Students should be aware that learning science should embody the ethical practices of formulating and evaluating scientific claims that are guided by scientific ethos/norms. This can increase the reliability of knowledge and its uses for good purposes.

2.1.2.1.3. Social Certification and Dissemination

This component ensures a “social quality control” and an “epistemic control” (Irzik and Nola 2014, p.1008) as well as providing scientific validation and dissemination of scientific knowledge. This component includes the collective and collaborative efforts of the community. Mainly, it involves the validation and distribution of scientific knowledge. Scientists gather the results of their investigations and do some professional activities, which were mentioned previously. They share their findings and engage with the broader scientific community. However, some scientists are quite secretive about their investigations for different reasons, such as to ensure priority, get recognition, and get credit for their work. Students should have a better understanding that scientists engage in community practices at all times, but this may have a tendency to lead to secrecy and competition. Similarly, teachers can draw an analogy between students’ and scientists’ attributes to emphasise the pros and cons of social-certification and dissemination process.

2.1.2.1.4. Social Values of Science

This component is comprised of respecting the environment, social utility and freedom (Erduran and Dagher 2014a; Kaya and Erduran 2016). Freedom is vital
for conducting scientific investigations, social utility is essential for receiving
support from the public, and respect for the environment is significant for human
survival. Freedom and respecting the environment are also involved in social
values as ethical principles. Students should be aware of the importance of freedom
because scientific investigations can be suppressed by different ideologies and
religions; also students should appreciate the contributions of research to the public
good. Furthermore, they should be conscious of not harming the environment in
the process of scientific investigations. All these are important to create responsible
citizens who can make unbiased public decisions without harming the environment
and by aiming for societal benefit.

2.1.2.1.5. Social Organisations and Interactions

This component explores the institutions that scientists work at, such as universities
and industrial sites are socially organised and interactively connected. There is also
an organisational hierarchy dominating this interaction. This interaction can be
either within the institution or between different institutions that scientists work at.
Within the institution, it can be among scientists, fellow researchers, PhD students
and so on. Between the institutions, it can be between universities, industry,
business initiatives, military and so on. Therefore, this category aims to increase
students’ understanding of:

what it means to be a scientist as an employee or an employer, and how the
institutional structures, dynamics and politics shape and form the interactions
among scientists working in and across organisations.

(Erduran and Dagher 2014a, p.146)

Furthermore, it can improve students’ understanding of science as an enterprise.

2.1.2.1.6. Political Power Structures

This component includes the relationships between science and race, science and
gender, and the politics of government/state and science (Erduran and Dagher
2014a). The relationship between the politics of government/state and science can
be exemplified by colonial science, which is the use of science as an ideological
tool to maintain political control over the colonies. Students should be aware of
how scientific knowledge can become a tool for oppression, exploitation, alienation
of individuals or groups such as gender discrimination, and destruction of ecologies and cultures when designated to serve gender, colonial, economic or other interests. Increasing awareness of political power structures in science education can contribute to creating responsible citizens who take responsibility for and who have the justice in their actions. Furthermore, it aids students to increase their critical thinking by realising how scientific knowledge is generated, used, and sometimes abused.

2.1.2.1.7. Financial Systems

This component explores how science and economics interact. Within this context, financial systems mention the role of economic forces on the actions of scientists, the distribution of resources in science and commodification and commercialisation of science, and the economic role of government and industry on scientific investigations (Erduran and Dagher 2014a). Scientists can work at universities, research institutions (non-profit or for-profit), industry, or they can establish their own companies to patent and produce a method or product. The scientific knowledge produced by scientists can be supplied to companies in order to contribute to new profit opportunities, such as creating new products. However, to conduct research, scientists need funding which operates within the standards and expectations of funding agencies and the scientific community. State/government also provides funding for scientific investigations, thereby influences the nature of scientific research. Students should be aware that science is not only a body of knowledge but also an institutionalised system with its economic factors and political agencies, and recognise how their contributions to state economy are used for funding scientific research. Improving this awareness can contribute to increase students’ success in getting research funding, and to create informed and educated public citizens.

The prominent scopes of these seven components are the places in which scientists work (organisations and institutes, such as universities, research centres, and industrial places), the activities which scientists exercise (for example the professional activities, and certification and dissemination of knowledge), the social values and ethos that they adopt, the role of government/state in science, and the role of economics in science. These scopes inform the visualisation of how
science operates in society in Section 3.3 of Chapter Three. In the next section, the reason for the choice of the theoretical framework is discussed.

2.1.2.2. Justification of the Framework of the Current study

Some of the critiques of contemporary foundational NOS approaches were presented above, and by utilising these critiques, the reasons for assigning the extended FRA as the theoretical framework of the current study are discussed. Table 2.4 summarises the contemporary foundational NOS approaches and their scope.

Firstly, other approaches do not meet the purposes of the current study because the “consensus view” is missing how economics and entrepreneurship (a) have an impact on science, (b) can be incorporated into these tenets, and (c) can be taught in science lessons (Allchin 2011, Matthews 2012). In “features of science”, there is no clear explanation of how economics (a) is covered by these features, (b) can be interwoven into these features, and (c) can be used as a “features of science” goal for classroom practice (Erduran and Dagher 2014a). Even though the “whole science” includes the economic dimension of science, this approach neglects some of the main aspects of EOS, such as commodification and commercialisation of science and economic dimension in the example activities of this approach is insufficient. In the FRA, there are very limited examples provided for the classroom practice. Hence, this approach does not fully satisfy the aims of the current study. All of the contemporary NOS approaches referred to science as an enterprise; however, none of them addressed the relationship between, science, EOS and entrepreneurship, and their role in NOS.
Table 2.4: Contemporary characterisations of nature of science in science education

<table>
<thead>
<tr>
<th>Authors</th>
<th>Proposed Approach</th>
<th>Characteristics of the Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abd-El-Khalick et al. (1998); McComas et al. (1998); Lederman et al. (2002)</td>
<td>Consensus View</td>
<td>Students should learn seven statements. These statements are mainly to teach that (1) scientific knowledge is tentative, theory laden, creative and imaginative, socially and culturally embedded, (2) observations and inference are different, (3) theories and laws are different kinds of knowledge and one does not become the other, and (4) there is no single scientific method to do science. Differentiation of observations and inference is important to make sense of inferential and theoretical entities and terms.</td>
</tr>
<tr>
<td>Allchin (2011)</td>
<td>Whole Science</td>
<td>Students should explicitly learn how science works (and how it sometimes does not), and why scientific methods and practices matter. Science teaching should comprise historical elements and science should be thought in an authentic and student-directed way by using contemporary case studies. Also, teaching needs to intertwine experimental/material, conceptual, and social strands of “doing science”.</td>
</tr>
<tr>
<td>Matthews (2012)</td>
<td>Features of Science</td>
<td>Students should learn about the features of science, which are empirical basis, scientific theories and laws, creativity, theory dependence, cultural embeddedness, scientific method, tentativeness, experimentation, idealisation, models, values and socio-scientific issues, mathematisation, technology, explanation, worldviews and religion, theory choice and rationality, feminism, and realism and constructivism. Also, educators should bring history, philosophy and sociology of science by asking simple questions and conducting basic research.</td>
</tr>
<tr>
<td>Irzik and Nola (2011); Irzik and Nola (2014)</td>
<td>Family Resemblance Approach</td>
<td>Students should learn the differences as well as similarities which defines the characteristics of science. Characteristics of science are categorised as the process of inquiry, aims and values, methods and methodological rules, scientific knowledge, professional activities, scientific ethos, social certification and dissemination of scientific knowledge and social values of science.</td>
</tr>
<tr>
<td>Erduran and Dagher (2014a)</td>
<td>The extended Family Resemblance Approach</td>
<td>Students should be encouraged in favour of their interests and understandings of science and nurtured with scientific perspectives. Characteristics of science are categorised as aims and values of science, scientific practices, methods and methodological rules, scientific knowledge, professional activities, scientific ethos, social certification and dissemination, social values of science, social organisations and interactions, political power structures, and financial systems.</td>
</tr>
</tbody>
</table>

Secondly, the extended FRA meets the purposes of the current study because it explicitly included the “financial systems” as one of the components of the extended FRA and presented example educational implications for each
component. Although “financial systems” includes the EOS-related words and has the EOS content, such as the inclusion of funding and commercialisation of science, Erduran and Dagher (2014a) did not provide an exclusive account of EOS. Moreover, Erduran and Dagher (2014a) stated that all components of the extended FRA are set to illustrate the scientific enterprise. They also reviewed science curriculum standards relating the extended FRA components and provided some examples for teaching. Based on the aim of the current study, the extended FRA does not only embrace the social aspects of NOS, such as the economic aspect but also includes and details a broader set of categories by exemplifying the transformation of the theoretical ideas into classroom practice. Due to all these reasons, the current study relies on the extended FRA proposed by Erduran and Dagher (2014a) as its theoretical framework.

Even though the extended FRA was defined as the theoretical framework of the current study, there were also some concerns related to this approach. For example, the reference to economics in interdisciplinary research areas, such as NOS, has been reasonably broad with nearly no theoretical input from the formal discipline of EOS (Erduran and Mugaloglu 2013; Kaya et al. 2018a, 2018b). Furthermore, there is no reference to entrepreneurship and the relevance of entrepreneurship to EOS and NOS. These issues are further discussed, and some possible solutions are proposed in Chapter Three.

Improving students’ understanding of EOS is one of the contemporary goals of science education (Erduran and Mugaloglu 2013). However, a substantial shortcoming of the contemporary NOS approaches (See Section 2.1.1) is to unveil the economic aspect of NOS and to implement the EOS into NOS and science education. Therefore, it is appropriate to draw the literature from EOS to explore how this formal discipline affects (a) the theoretical characterisation of science, (b) the operation of science, and (c) the practical implications of science teaching and learning. Thus, in the next section, the formal discipline of EOS is introduced, the aspects/scopes of EOS are explored conceptually by providing the literature from its formal discipline. Furthermore, the place of EOS in science education is identified in the next section.
2.2. ECONOMICS OF SCIENCE

This section introduces EOS in order to explore the relationship between EOS and NOS in science education and characterises science by providing the literature from the formal field of EOS. This section also aims to prepare the foundation to problematise the “financial systems” in the extended FRA in Chapter Three. The section starts with a historical look at EOS as there is limited exploration of EOS in science education literature. By the inclusion of this historical background, the literature from the history of EOS may be integrated into science education research with the awareness of its background. Then, the scopes of EOS are specified and thematised systematically and explored through the organisational and economic dynamics that govern scientists and scientific communities. The section finishes by presenting the relevant science education literature on EOS to help to identify the role of EOS in NOS and science education.

Economics is a field, which has been researched and discussed for centuries. In ancient times, economics has been thought of as a philosophical idea. For example, Plato’s dialogue *The Republic* (c. 380-360 BC) is known as one of the oldest written resource related to economics. Although how science and economics affect each other can be seen in history (e.g. in the Industrial Revolution), the term “economics of science” has only been used recently. Although there is no certain information about the first user of the term, it is known that one of the first uses was by Charles Sanders Peirce to argue the social organisation of scientific research by using an economic model at the end of the 19th century (Wible 1994).

Even though economists had little or nothing to say about the social structure of science before the 20th century, in particular prior to World War II, economics has recently become prominent in science-related fields (Mirowski and Sent 2008). Whilst academic contribution to World War I was mostly limited to using universities for training facilities and providing researchers for working in the government labs, strong university - government relationship emerged in World War II due to military research projects (Etzkowitz 2008). During World War II, many academics were transferred to well-equipped labs with research and development (R&D) aims. Furthermore, universities and industrial firms started to subsidise individual scientists as well as providing jobs in a federal laboratory
system (Mirowski and Sent 2008). This might be a precursor of the relationship between university, industry and government relationship. The university was supported by the government in agriculture (mid-19th century), the military (World War II), and industry (the 1970s) (Etzkowitz 2008). In the late 1970s, there were some physicists providing funds from stock options in the semiconductor industry. These scientists were not purely in the scope of academic or industrial scientist definitions; they were called “entrepreneurial scientists” (Etzkowitz 2008; Johnston and Edwards 1987). Industrialisation and the emerging relationship between university, academia and government expedited the commodification and commercialisation of science. In consequence of commercialisation, property rights and ownership issues resulted in conflicts in the 1980s. Legislation of the Bayh-Dole Act resolved the ownership issue in the USA due to intellectual property rights arising from the research conducted at universities and funded by the government (Etzkowitz 2008).

According to Sent (1999), EOS has gone through three stages; Mertonian sociology of science, the old economics of science and the new economics of science. She explained that in the period of the Mertonian sociology of science, EOS was influenced by the political implications of controversies and movements, such as the discussions on the necessity of rationalising the organisation of science, and Polanyi, Popper and Merton’s views. As previously mentioned in section 2.1.2.1, Merton is important in science since the Mertonian norms are the institutional imperatives involving the ethos of modern science (Erduran and Dagher 2014a; Irzik 2007). Other than this, Merton pioneered the topics in EOS, such as reward structures and scientists’ career paths, while disagreeing with science as a market-driven process. In the old economics of science period, it has been discussed whether science is a public good (Sent 1999). Some researchers believed that science is a public good due to its characteristics such as uncertainty and risks, some others supported that it is a public good due to its diversity and flexibility (Callon 1994).

This period included:

- an institutional approach to science, an argument that science is a market, a unity-of-science approach and a clear definition of the organisational framework of scientific research.

(Sent 1999, p.101)
The new economics of science involved a contextual approach to science, arguing whether science can be commodified and questioning the organisation in science. Sent (1999) was of the opinion that the new economics of science view is increasing due to the upsurge in distress of the status of EOS and also the need for improved understanding of the social and institutional structures of scientific research to conduct informed arguments about critical issues in economics. She stated the assumptions of the new economics of science as that:

1. It is more inclined to analyse the institutional structures of scientific research, be they the various modalities of funding, forms of dissemination, disclosure and validation of findings, or determinants of ‘market’ versus non-market coordination schemes.
2. It is less inclined to treat knowledge as a generic commodity; and more willing to acknowledge the central place of tacit knowledge.
3. It rejects the unilinear model of ‘basic science-applied science-technology’.
4. It tends to look to innovations in the field of industrial organisation theory for inspiration.
5. It extends economic analysis to aspects of science, such as the extent of quantification, the allocation of measurement error, the economics of electronic publishing and the economics of fraud.
6. It recasts the earlier misleading dichotomy between public subsidy and private support into a richer interplay between corporations (including foundations), academic institutions and government, each of which exhibits public and private attributes to varying degrees. Appreciation of this point leads directly to re-evaluations of the question whether different funding structures are more or less appropriate to different phases of the process of scientific innovation.

(Sent 1999, pp.102-103)

In the social-institutional system of science, Erduran and Dagher (2014a) referred to similar assumptions as identified by Sent (1999). For example, Sent (1999) mentioned the institutional structures of scientific research, and Erduran and Dagher (2014a) referred to this as the social-institutional system of science. Sent (1999) mentioned the various modalities of funding and innovation, and Erduran and Dagher (2014a) proposed the “financial systems” which includes these modalities. Forms of dissemination and validation of findings were mentioned by Sent (1999), and this is referred as social certification and dissemination by Erduran and Dagher (2014a). Sent (1999) addressed the government’s influence on academia, which was referred to in the “political power structures” by Erduran and Dagher (2014a).
However, even though the assumptions of the new economics of science were referred in the SIS of science in the extended FRA by Erduran and Dagher (2014a), some of the assumptions were neglected, incomprehensive or not well-informed. For example, even though the innovation was mentioned in the SIS of science, there was no elaborated information presented related to it. Furthermore, the government’s influence on academia was addressed, but the interplay between corporations, academic institutions and the government was not represented. The role of the market is also overlooked in the SIS of science even though it was involved in the assumptions of the new economics of science. In addition to these assumptions stated by Sent (1999), Diamond (2008) explained the aims of science and stated that:

\[
\text{economics of science aims to understand the impact of science on the advance of technology, to explain the behaviour of scientists, and to understand the efficiency and inefficiency of scientific institutions.}
\]

(Diamond 2008, p.1)

Similar to these aims of EOS, Erduran and Dagher (2014a) discussed the impact of science on technology, the behaviour of scientists and the scientific institutions within the context of SIS of science in the extended FRA. The relevance of EOS to NOS and its similarity to “financial systems” in the SIS of science are evident in the literature presented. However, to examine the structure of the “financial systems” in the extended FRA, the appropriate scopes of EOS to NOS should be clarified. Therefore, the next sub-section aims to specify and theme the scope of EOS systematically while examining them.

### 2.2.1. The Scopes of Economics of Science

This section specifies and thematises the scopes of EOS systematically and investigates each scope of EOS. During the 20th and 21st century, there have been many studies conducted on EOS (Audretsch et al. 2002; Diamond 2008; Erduran and Mugaloglu 2013; Irzik 2007; Mirowski and Sent 2008; Romer 2001; Stephan 1996). Between these studies, the most dominant themes in the science education context are science and scientists in the industry, funding of research at academic institutions, and commodification and commercialisation of science (Kaya et al. 2018b). These themes are examined respectively in the following paragraphs.
2.2.1.1. Science and Scientists in Industry

*Science and scientists in the industry* refer to the relationship between science and the industry and have been examined by many researchers (Diamond 2008; Etzkowitz 2008; Irzik 2007; Mirowski and Sent 2002, 2008; Polanyi 1957; Radder 2010; Romer 2001; Stephan 1996). These studies emphasised the contribution of science and scientists to sustaining the development of industrial places and institutions such as universities (Kaya et al. 2018b). For example, Stephan (1996) showed the relationship between science and the industry by addressing that most doctoral scientists in the USA are employed in business, industry and institutions of higher education. Some researchers criticised the growth of the university and the industry relationship due to the belief that the institutional logic of science and industry are incompatible (Shenk 1999; Slaughter and Leslie 1997; Slaughter and Rhoades 2004). However, some others supported this relationship due to, for example, having a new “mode of knowledge production” (Gibbons et al. 1994) and a “triple helix”, which is the link between the government, university and industry (Etzkowitz 2008). Furthermore, Vallas and Kleinman (2007) highlighted the interwoven nature of these two domains. Likewise, the sixth new economics of science assumption by Sent (1999), as outlined previously, is the interplay between the corporations, academic institutions and the government.

The cooperation of scientists and engineers during World War II brought new goals, such as expanding the capability of academic research and cooperating with industry (Etzkowitz 2008). After World War II, the university-industry divide started to become less distinctive (Sent 1999). According to Etzkowitz (2008), contemporary university-industry relationships emerged from the funding of basic research, an industrial project requiring academic input and joint formulation of research programmes. There can be different kinds of supply and demand relationships between science and industry. Two examples of such relationships are presented here. In the first relationship, academia supplies graduates or advises the scientific research or projects conducted in the industry (Stephan 1996). For instance, the European Study Group with Industry (ESGI), which originated in Oxford in 1968, has been held several times a year across Europe. ESGI aims to increase the interaction between mathematicians, scientists and industry and to
solve four to eight real industrial problems declared by companies at the event. In this example, academia is the supplier, and industry is the demander.

In the second relationship, industry supplies funding for research (Stephan 1996) and academia is the demander in this case. For example, Horizon 2020, which is the biggest EU research and innovation programme, provided billions of dollars from industries to academic institutions for funding research. Other than these two relationships, academia and industry can also work together. Some professors work at a university and company at the same time (Irzik 2007, 2013; Mirowski and Sent 2002; Stephan 1996). Numerous scientists are employed in the private sector as CEOs, or they run their own business while continuing to work at the university (Irzik 2007). Based on academic inventors’ publications and their interactions with scientists in industry, technology transfer offices identify commercial opportunities. These offices also support the transfer of these technologies from academia to the private sector through the industry and educate faculty members in the utilisation of their research (Etzkowitz 2008; Van Norman and Eisenkot 2017a, 2017b). When a university is successful at technology transfer, this university has more opportunities for providing more funding and exchanging required materials, information and personnel with private industry (Van Norman and Eisenkot 2017a, 2017b). This improves research opportunities for their faculty members and students.

This relationship between science and industry usually has a third partner – the government. The government plays a crucial role in university-industry interactions in different ways such as changing the patent laws and providing research grants as “public venture capital” for start-ups. According to Mirowski and Sent (2008), the government is the one who changed the understanding of the relationship between science and industry characteristic of the interwar time in the form of military. Other than these, the university obtains additional resources from industry and the government to improve the research quality (Etzkowitz 2008). The industry and the government may also provide funding to the universities that move the findings toward utilisation.
2.2.1.2. Funding of Research at Academic Institutions

*Funding of research at academic institutions* has a crucial role in society to utilise scientific research. Although industry was important in innovating new forms of science funding and management during World War II, government and military funding significantly increased following the wartime (Mirowski and Sent 2008). Moreover, due to globalisation, the industry started to provide research funding more than the government did (Carter 2008). Universities may be funded for academic research by the government, research centres, business organisations and/or industry. In the USA, usually, the federal government, business and industry supply funding for R&D at universities. The government funds the scientific research due to its importance to defence and economic growth and due to the need to subsidise the production of knowledge for the public good, and the business and the industry fund the scientific research due to their desire to innovate (Stephan 1996).

There are different ways of acquiring funding, such as acquiring funding through scientists’ own institutions or by applying for a grant to funding agencies (Kaya et al. 2018b). Different sources, such as government grants, may provide funding to different institutions, such as research centres and universities. When acquiring funding through scientists’ own institutions, scientists obtain the funding for their scientific research through their institutions, such as research centres and universities. Some benefits of this type of funding acquirement may be that scientists can spend all their time on their research rather than spending time writing research proposals and completing application forms. Sometimes industries or the private sector may also offer to fund the universities in exchange for the results of scientific research, and for the shared and sole ownership of patents (Erduran and Mugalglu 2013; Irzik 2007; Radder 2010). When acquiring funding by applying to funding agencies for a grant, scientists submit their proposals for grant applications. Scientists may receive funding at the end of a competitive application process. The scientists who follow the grant application process take on the many characteristics of entrepreneurs (Stephan 1996), such as pursuing opportunities and being innovative. Some benefits of the grant application process are that the peer-reviews promote the quality and sharing of information rather than secrecy (Erduran and Dagher 2014a; Irzik and Nola 2014).
Nonetheless, due to the reward structure\textsuperscript{6}, secrecy in research can increase. Furthermore, sometimes the government funding and the reward structure may drive the research even though one of the main purposes of science is the pursuit of knowledge driven by curiosity. This may result in changes in scientists’ research interests or the scientific domains, for example, scientists may conduct research towards the topics and domains in which more funding is available (Kaya et al. 2018b). Both forms of acquiring funding may be adopted within the same country, as is the case in Europe.

However, this financial relationship between academia and industry can have a negative impact on research studies. For example, Resnik and Elliott (2013) researched the influence of financial relationships on the research credibility. They found that financial relationships should be considered when evaluating research because these relationships can affect different aspects of scientific investigations, such as study design, data collection, and data analysis. In another research, it has been found that although a faculty, which obtained more of its funding from the industry, had more peer-reviewed publications than a faculty without such funding. Yet, the faculties that have industrial funding were less academically active than the others (Van Norman and Eisenkot 2017a, 2017b). Another impact of industry funding on scientific research is that researchers delay dissemination of their research outcomes in order to “protect their scientific lead” (Van Norman and Eisenkot 2017a, 2017b). This can be an example of monopolisation of research. Economic factors can also influence the government-funded research as well as the research funded by the private sector. Distribution of grant money is determined by the role of government, which may promote or limit various scientific domains and conceivably identify successful commercialisation of technology. Funding opportunities for scientists have also been increased by the commodification and commercialisation of science (Irzik 2007).

\subsection*{2.2.1.3. Commodification and Commercialisation of Science}

The role of science and scientists in the industry and the funding of research at academic institutions affected the growth of \textit{commodification and commercialisation of science}

\textsuperscript{6} The reward structure is further discussed later on in the commodification and commercialisation of science, which is one of the scopes of EOS.
commercialisation of science (Etzkowitz 2008; Irzik 2007, 2013; Oliver 2004; Vallas and Kleinman 2007). Commodification and commercialisation of academic research have recently gained some interest worldwide and have been explored by a number of researchers. For example, according to Irzik (2013), the commercialisation of academic science is concerned with the fact that:

academic scientific research is being done increasingly for profit and that its results are commodified through mechanisms of intellectual property, primarily patents, copyrights and licencing

(Irzik 2013, p.2376)

Likewise, Radder (2010) claimed that commodification and commercialisation of science have a close relationship with academics selling their expertise and the results of their inquiries. According to Oliver (2004), the relationship between academia and industry has an impact on the growth of commercialisation of academic science and the transformation of research results into intellectual properties/patents as marketable commodities. Thus, the definition of the commercialisation of science adopted in the current study is turning the results of the scientific knowledge into marketable commodities by the mechanisms of intellectual property.

Although there are discussions about the incompatibility of science and industry as previously mentioned, some researchers claim the opposite (Powell and Owen-Smith 2002). This convergence and commercialisation of academic science can have a positive or negative impact on scientific research. On the one hand, commercialisation of science contributes to increasing innovation facilities of the universities and to enabling new job opportunities (Etzkowitz 2008). It also empowers the university-industry relationship, the capitalisation of knowledge and economic and social development (Irzik 2007, 2013; Mirowski and Sent 2008). Additionally, commercialisation of science allows funders of the research projects to make profits through research that increases the funding opportunities for scientists. On the other hand, as stated by Irzik (2013), the commercialisation of science and its unfavourable impacts on various disciplines, in particular on biomedicine, can be seen clearly at different levels. Commercialisation is incompatible with open science, and as a result, secrecy can emerge which conflicts with the ethos of science. Likewise, research interest can be shaped by commercial
and corporate interests, and research findings can be biased in order to obtain funding and reward systems in science may be affected (Irzik 2007, 2013; Krimsky 2004; Resnik and Elliott 2013; Van Norman and Eisenkot 2017a, 2017b).

A common understanding is that science is a public good due to its diversity and flexibility (Callon 1994). Nevertheless, privatisation of knowledge has been increasing recently due to technological advances and the commercialisation of science. A non-market reward structure in science aims to incentivise scientists to behave in a socially more responsible way to produce the public good “knowledge”. Based on Stephan (1996), Kaya et al. (2018b) identified three kinds of reward structures:

1. Priority: This involves the award of priority of discovery and publication, which are also relevant to recognition. Some of their different forms are eponymy and Nobel Prize. Priority creates a form of intellectual property, and financial rewards can be one of the consequences of priority.

2. Property rights: This type of reward structure defines how a resource is used and by whom it is owned. Intellectual property rights are included in this category. Patenting, copyrights and licencing are some examples of the property rights. Financial remuneration can be one of the outcomes of this.

3. Financial remuneration: This includes publishing or citation value, salary, prize money, and speaking and consultation fees. For example, in Turkey, when researchers publish in internationally indexed journals or receive citations, they may receive financial remuneration from the scientific and technological research council of Turkey. This strategy is also quite prevalent in academic institutions in Australia.

Kaya et al. (2018b, p.462)

Many issues can also emerge regarding the reward structure. These issues can be about the ownership of the product, negotiation of contracts with the industry and the government, monitoring the human subjects and dangerous materials research (Mirowski and Sent 2008). Furthermore, the reward structure can result in scientific contests, inequality, a patent race (Stephan 1996), fraud, only targeting financial awards when publishing, the monopoly of research and secrecy. Based on these points and the relationship between science and industry, how scientific effort is organised, monitored, used and rewarded in the industry is of importance.

The commercialisation of academic research started the transformation of research into products and new enterprises (Etzkowitz 2008). To facilitate the commercialisation of academic research, the US government started three main
schemes, which are setting up incubator units, supplying high-technology resources for academic and start-up companies, and providing platforms to strengthen the link between academia and industry (Etzkowitz 2008; Etzkowitz and Leydesdorff 1998, 2000; Oliver 2004). Incubator units, which are multi-disciplinary programmes or units located in academia, are to bring students together across disciplines.

Although the incubator is traditionally defined as a support structure, providing common services to support firm-formation, incubation is fundamentally a method of training a group of individuals to work well together as an organisation.

(Etzkowitz 2008, p.105)

These units are a part of technology transfer activities at universities, and they are funded mainly by the government and partially by the industry. Also, one of the ways of transferring technology into the commercial sector is the university-to-business model. In the university-to-business model transfer, research universities support commercialisation of science, and many universities assist intellectual property protection, licencing, formal support for the entrepreneurial activities of faculty through different programmes such as business incubators or enterprise development programmes (Bird et al. 1993). The government also see the universities - the ones that are supported by incubator facilities - as a source of economic growth and renewal (Etzkowitz 2008).

Thus far, scopes of EOS have been identified. The next section aims to present the science education literature relating EOS to identify the importance of EOS in science education.

2.2.2. Economics of Science in Science Education

This section reviews and discusses the literature that refers to the economic aspect of science and the scopes of EOS in science education. There are some national and international studies that implicitly or explicitly refer to the scopes of EOS in science education and express the importance of economic aspect in science

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7 The scopes of EOS were presented in Section 2.2.1. as science and scientists in the industry, funding of research at academic institutions and commodification and commercialisation of science.
education (Carter 2008; Erduran and Mugaloglu 2013; Irzik 2007, 2013). In this section, four main areas relating to EOS in science education are explored. These are economic perspectives, scopes of EOS, national studies referring to EOS and EOS content in NOS in science education.

Firstly, concerning the economic perspectives in science education, Carter (2008) investigated the changes in science due to the emergence of the economic and socio-political relationship between science, the nation, state, and private commercial interests. As well as investigating this relationship, she also explored the impact of these changes on the development of science education. She stated that examining this relationship in depth is of importance in science education since:

> it can help formulate new questions, and methods for their investigation, relevant to the work of science education in the newly global world.

(Carter 2008, p.617)

Carter (2008) also found that education has been restructured by different factors, such as ideologies, and science has been changing due to globalism. Furthermore, there are implications of globalism on enterprising science for science education. She supported developing science education that values non-commodified forms of knowledge, relationships, activities, and aspects of life. Erduran and Mugaloglu (2013) also emphasised the importance of EOS in science education. They presented two rationales for examining the intersection of EOS and science education. The first rationale was that economic features of science are relevant to the characterisation of science. The second rationale was that the development and training of future scientists are reliant on the foundation and the maintenance of the scientific enterprise through the education system. That is, both science education and EOS contribute to each other. They also provided an example activity on the commodification of science in the context of using modelling in science education and conducting argumentation in science education. This example activity was to be used in second-level education, which includes students aged 12 - 18 approximately. This activity is aligned with the aims of the current study and therefore is utilised during the development of research instruments in Section 4.4.2.1.
Secondly, regarding the scopes of EOS in science education, Irzik (2013) discussed the relevance and impact of the commercialisation of academic science on science and science education. He was of the opinion that EOS is a necessary research domain since science is an enterprise, which is affected by all social factors including economic factors. Furthermore, he stated that:

science has a huge economic dimension, the examination of which can contribute significantly to a deeper understanding of NOS, in line with the recent emphasis on learning and teaching “science in context” or “authentic science”.

(Irzik 2013, p.2382)

Thirdly, between the national studies, DES (2004) addressed the relationship between economy and education within the context of the Irish education system and stated that:

there is a growing recognition, particularly in the European Union, that the provision of quality education and training is central to the creation of a high-skills, knowledge and innovation-based economy that will underpin ongoing and sustainable prosperity.

(DES 2004, p.7)

Furthermore, DES (2016) referred to economics as one of the future national skills in Ireland, which will be required in all levels of education by 2025.

Fourthly, the content of EOS is also referred to in the context of NOS within the science education literature. There are some studies implicitly or explicitly referring to some of the scopes of EOS, such as funding, in NOS (Allchin 2011; Allchin et al. 2014; Erduran and Dagher 2014a; Irzik and Nola 2011, 2014; Kaya and Erduran 2016; Lederman et al. 2002; Matthews 2012). Nevertheless, between these studies, the reference to EOS is implicit or rather weak and superficial (See Section 2.1.1). Although one of the most profound studies in NOS is a book written by Erduran and Dagher (2014a), they did not use the term “economics of science”. Instead, as mentioned earlier, they used the term “financial systems” in the SIS of science involving the elements of EOS, such as funding of research at academic institutions and scientific enterprise. The issues emerging related to the “financial systems” are discussed in Section 3.1. They presented two rationales for having financial intelligence in science education. Firstly, this inclusion increases
students’ awareness of institutionalised system of science that is tied to economic factors and political agencies and thereby students’ research funding culture of academic and research institutions is facilitated. Secondly, it is crucial to creating informed and educated public citizens who are mindful of socio-economic issues and aware of how their taxes are used for funding in scientific research. Furthermore, they provided examples for teaching science in its social context and reviewed three national documents: two curriculum standards from the US and one from England. They found that although the US documents do not have an explicit reference to economics, the document from England has an explicit reference to economics.

The relevance and importance of EOS to NOS have been explored and explained as being one of the contemporary aspects in the characterisation of science. Even though there is research conducted nationally and internationally on the elements of EOS in NOS and science education, the research profoundly and explicitly examining the role of EOS in NOS and science education through the formal discipline of EOS is rare. For example, Kaya et al. (2018b) examine this aspect theoretically but do not provide any research findings. Thus, the current study diverges from the other studies by investigating the relevance and inclusion of EOS to NOS in science education, conducting empirical research and presenting educational applications. The current study also presents EOS in NOS and science education in a more structured way and informs the NOS for science education research by the formal discipline of EOS. This is discussed further in Section 3.1. However, to do this, in the following section, entrepreneurship is introduced and defined as another contemporary aspect of science due to its relationship with economics and science.

2.3. ENTREPRENEURSHIP

This section aims to define and introduce entrepreneurship in its formal field to start realising the relationship between entrepreneurship, EOS and NOS in science education as well as aiming to prepare the foundation to argue the issues in the “financial systems” in NOS. The section starts by presenting the relevance of science and economics to entrepreneurship and the relevance of entrepreneurship to science education. Next, entrepreneurship is introduced by presenting the
changes in entrepreneurship theory and explaining the term “entrepreneur” from a historical perspective. This historical inclusion contributes to defining the entrepreneur and entrepreneurship in its formal context and enables the comprehension of the relationship between science and entrepreneurship. Then, how entrepreneurship is defined in its formal field is presented, and entrepreneurship is re-defined in the NOS and science education context. The section is concluded by presenting the relevant science education literature on entrepreneurship to help identify the role of entrepreneurship in NOS and science education.

Recently, the relationship between science, economic growth and entrepreneurship has been discovered (Etzkowitz 2008; Sanders 2007), and entrepreneurial universities have emerged. For example, Massachusetts Institute of Technology (MIT) is one of the first entrepreneurial universities with its technology transfer offices and establishment of businesses (e.g. Dropbox and Intel) out of its research activities (Etzkowitz 2008). Entrepreneurial universities aim to contribute to the social and economic development of the country. Furthermore, the logic behind the operation of academic institutions and entrepreneurial practices in the marketplace have been combined and therefore academic scientists have adopted entrepreneurial orientations (Vallas and Kleinman 2007). However, the entrepreneurial perspectives of commercial laboratories affected the academic norms adopted by scientists. Also, Vallas and Kleinman (2007) pointed to the issue of the infusion of an entrepreneurial ethos in academic science. The issue of how entrepreneurial orientation influences scientific practice is of importance for further exploration (Stephan 1996). There is also some research highlighting the enterprising features of science. For instance, as mentioned in section 2.1.2, according to Irzik and Nola (2014), science is seen as an enterprise with an economic dimension. Likewise, Erduran and Dagher (2014a) found that the social-institutional context of science embraces science as an enterprise. Thus, it can be inferred that economic features of science and the maintenance of the scientific enterprise have an impact on the characterisation of science (Erduran and Dagher 2014a; Irzik and Nola 2014). Peters-Burton and Baynard (2013) advocated the importance of scientific enterprise by stating that:
an understanding of the scientific enterprise is useful because citizens need to make systematic, rational decisions about projects involving scientific endeavours and technology.

(Peters-Burton and Baynard 2013, p.2801)

Many studies have been conducted on entrepreneurship in science\(^8\) and entrepreneurial scientists (Annetta et al. 2017; Deveci and Seikkula-Leino 2016; Jiang et al. 2017; Johson and Amiraly 2017; Martin et al. 2017). By acting as entrepreneurs, universities and governments demonstrate that entrepreneurship is not limited to business (Etzkowitz 2008). Different people can become entrepreneurs as well as business people, for example, academics, engineers and inventors. Nevertheless, the role and importance of entrepreneurship and entrepreneurial scientists in the SIS of science and science education are underrepresented. Thus, entrepreneurship is introduced in the next section.

### 2.3.1. Changes in the Term Entrepreneur

This section presents the changes in entrepreneurship theory and the term entrepreneur from a historical perspective. The roots of entrepreneurship can be traced back to the 13\(^{th}\) century, with the use of an entrepreneur in the meaning of “go-between” in French for Marco Polo, who was a merchant-adventurer. Starting from the middle ages, the development of entrepreneurship theory and the definition of an entrepreneur are presented in Table 2.5.

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\(^8\) The concept of entrepreneurship is further examined and elucidated in section 2.4. The aim of mentioning entrepreneurship here is to show its relationship with science and economics.
<table>
<thead>
<tr>
<th>Timeline</th>
<th>Definition of entrepreneur and entrepreneurship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle Ages</td>
<td>An actor and a person in charge of large-scale production projects.</td>
</tr>
<tr>
<td>17th Century</td>
<td>A person bearing risks of profit (loss) in a fixed price contract with the government.</td>
</tr>
<tr>
<td>1725</td>
<td>Richard Cantillon – a person bearing risks is different from one supplying capital.</td>
</tr>
<tr>
<td>1803</td>
<td>Jean Baptiste Say – separated profits of entrepreneur from profits of capital.</td>
</tr>
<tr>
<td>1876</td>
<td>Francis Walker – distinguished between those who supplied funds and received interest and those who received profit from managerial capabilities.</td>
</tr>
<tr>
<td>1876</td>
<td>Joseph Schumpeter – an entrepreneur is an innovator and develops an untried technology.</td>
</tr>
<tr>
<td>1934</td>
<td>David McClelland – entrepreneur is an energetic, moderate risk taker.</td>
</tr>
<tr>
<td>1961</td>
<td>Peter Drucker – entrepreneur maximises opportunities.</td>
</tr>
<tr>
<td>1964</td>
<td>Albert Shapero – an entrepreneur takes the initiative, organises some social and economic mechanisms, and accepts risks of failure.</td>
</tr>
<tr>
<td>1980</td>
<td>Karl Vesper – an entrepreneur is seen differently by economists, psychologists, business person, and politicians.</td>
</tr>
<tr>
<td>1983</td>
<td>Gifford Pinchot – intrapreneur is an entrepreneur within an already established organisation.</td>
</tr>
<tr>
<td>1985</td>
<td>Robert Hisrich – entrepreneurship is the process of creating something different with value by devoting the necessary time and effort; assuming the accompanying financial, psychological, and social risks; and receiving the resulting rewards of monetary and personal satisfaction.</td>
</tr>
</tbody>
</table>


Summarising the table, although in the Middle Ages an entrepreneur was seen as a project manager rather than a risk taker, in the 17th century it started to be seen as a risk taker because any profits and losses belonged to the entrepreneur due to having a fixed-price contract with the government. In the 18th century, a capital provider and capital taker were differentiated from each other due to industrialisation. That is, an entrepreneur was distinguished from venture capitalists. In the 19th century, entrepreneurs mostly seen as the person who organises and operates an enterprise by not inventing but adapting and developing
new technology for economic development (Hisrich and Peters 2002). In the 20th century, entrepreneurs were seen as innovators.

According to Schumpeter (1952):

> the function of the entrepreneur is to reform or revolutionise the pattern of production by exploiting an invention or, more generally, an untried technological method of producing a new commodity or producing an old one in a new way, opening a new source of supply of materials or a new outlet for products, by organising a new industry.  

(Schumpeter 1952, p.9)

Thomas Edison, a scientist who lived from 1847 to 1931, is also one of the examples given as an entrepreneurial scientist due to the incubator programme that he used (Etzkowitz 2008). Due to many of his inventions including a battery for the electric car and electric light, it can be said that he would fit into the definition of a 20th-century entrepreneur. The definition of an entrepreneur has been changed throughout history, based on the needs and changes in the world, such as industrialisation and globalisation. Therefore, the definition of entrepreneurship has also been changed to align with the definition of an entrepreneur. That is, entrepreneurship is different from being an entrepreneur. While an entrepreneur refers to a person, entrepreneurship predominantly refers to a process. In the next section, different definitions of entrepreneurship in the 20th and the 21st century are presented.

2.3.2. Defining Entrepreneurship in its Formal Discipline

This section identifies the different definitions of entrepreneurship in the 20th and the 21st century to lead the way to re-define entrepreneurship in the NOS context. Even though there are many studies defining entrepreneurship in its formal field, there is still no consensus on which definition to follow. The European Commission has been focusing on the role of entrepreneurship in education for the last few decades. The European Commission (2004) presented two concepts of entrepreneurship teaching; namely a broader and more specific concept. Although a more specific concept focuses on how to start a new business (Bruyat and Julien 2001), a broader concept focuses on personal qualities and environment rather than new venture creation. Since the context of the current study is science education,
the broader concept of entrepreneurship is considered within the science education context. Table 2.6 demonstrates how entrepreneurship has been defined in its broader concept during the 20th and 21st century.

Table 2.6: Developing of entrepreneurship theory in chronological order

<table>
<thead>
<tr>
<th>AUTHORS</th>
<th>DEFINITIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Schumpeter (1934)</td>
<td>Carrying out new combinations of a firm organisation including new products, new services, a new source of raw materials, new methods of production, new markets, new forms of organisation and so on.</td>
</tr>
<tr>
<td>Hoselitz (1952)</td>
<td>Coordination of productive resources, an introduction of innovations and the provision of capital.</td>
</tr>
<tr>
<td>Timmons (1989)</td>
<td>The ability to create and built something from practically nothing, it is initiating, doing, achieving and building an enterprise or organisation rather than watching, analysing or describing one.</td>
</tr>
<tr>
<td>Shane and Venkataraman (2000)</td>
<td>To understand how opportunities to create something new arise, and are discovered or created by specific individuals who then use various means to exploit or develop them.</td>
</tr>
<tr>
<td>Hisrich and Peters (2002)</td>
<td>The process of creating something different with value by devoting the necessary time and effort; assuming the accompanying financial, psychological, and social risks; and receiving the resulting rewards of monetary and personal satisfaction and independence.</td>
</tr>
<tr>
<td>Allen (2003)</td>
<td>The process of organising. This organisation process includes committing resources to an opportunity; establishing procedures for the use of resources; identifying, assembling and configuring resources; and interacting with people and coordinating and establishing routines.</td>
</tr>
<tr>
<td>Birdthistle et al. (2007)</td>
<td>To transfer the knowledge, service or product between the fields of inquiry.</td>
</tr>
<tr>
<td>Rindova et al. (2009)</td>
<td>Efforts to bring about new economic, social, institutional, and cultural environments through the actions of an individual or group of individuals.</td>
</tr>
</tbody>
</table>

According to Shapero (1975):

in almost all of the definitions of entrepreneurship, there is agreement that we are talking about a kind of behaviour that includes: (1) initiative taking, (2) the organising and reorganising of social and economic mechanisms to turn resources and situations to practical account, (3) acceptance of risk or failure.


In Table 2.6, although organising, initiative taking and risk-taking skills can be seen clearly, there is no such emphasis on failure, which is emphasised by Shapero (1975). Learning about failures in science is essential in science education (Allchin 2011); therefore this should be considered as a feature when defining entrepreneurship in the context of NOS. Furthermore, realising opportunities is
another common word in Table 2.6. Although this word was not used in definitions up until the 1980s, it has been used frequently since then. Based on the definition of entrepreneurship in its formal field, entrepreneurship is defined in the context of NOS in the next section.

2.3.3. Entrepreneurship in the Context of NOS

This section re-defines entrepreneurship in the NOS context based on the definitions of entrepreneurship and its common characteristics. Even though entrepreneurship is defined in its formal field, there is a lack of research on defining entrepreneurship in the context of NOS and science education. Therefore, the current study contributes to science education by re-defining entrepreneurship in the context of NOS. Entrepreneurship is of relevance to NOS because there is a relationship between science, economic growth and entrepreneurship (Etzkowitz 2008; Sanders 2007). Furthermore, as mentioned in Section 2.1, science is also characterised as an enterprise with an economic dimension (Erduran and Dagher 2014a; Erduran and Mugaloglu 2013; Irzik and Nola 2014, p.8). This relationship influenced the increase in the number of entrepreneurial universities, which aim to contribute to the countries’ social and economic development. Due to this relationship between entrepreneurship, economics and science, entrepreneurship is re-defined in the context of NOS based on the broader definitions of entrepreneurship presented in Section 2.3.2.

Figure 2-4: Illustration of frequently used words in defining entrepreneurship
Based on the analysis of words frequently used in the definitions of entrepreneurship (See Figure 2-4) and based on the definitions of Rindova et al. (2009, p.477), Shane and Venkataraman (2000, p.218) and Birdthistle et al. (2007), entrepreneurship (See Table 2.6), in its broader context, is re-defined for NOS in the context of SIS of science in the current study. Furthermore, as previously mentioned, by being conscious of the importance of emphasising the possibility of failures in science, the phrase “possible failures” is also added to the definition. In the current study, entrepreneurship in NOS is defined as:

the process of establishing new economic, social, institutional, cultural and scientific environments or organisations to create future products and services by realising the opportunities and their possible failures and using required resources.

(Kaya et al. 2018a, 2018b)

Based on this definition, entrepreneurship is also explained as a process in the context of NOS in the following classic example of entrepreneurship. This example, adapted by the researcher from the invention of iPhone, refers to the links between scientists, engineers, entrepreneurs and the market (Pierce 2018). A scientist discovered the scientific knowledge behind the touchpad, and by using this knowledge, an engineer invented the touchpad. Another scientist or engineer invented and patented activating the screen-lock by sliding back and forth. Steve Jobs, as an entrepreneur, merged these patents and launched the iDevices, such as the iPhone, as a new product. In this example as in the definition of entrepreneurship in NOS as defined in the current study, someone realised an opportunity in the market, considered the possibility of failure and established a company by using required resources and combining the patents. In this company, this person developed new products and distributed them in the market. This person is called an entrepreneur according to Table 2.5, and the whole process is called entrepreneurship according to the definition of entrepreneurship in NOS context. Furthermore, scientists, engineers and entrepreneurs utilised each other’s work during the process, which also affected the market and society. Thus, this is just one example of entrepreneurship in science, particularly in a NOS context.

Scientists and entrepreneurs are usually thought to have different aims, values and working ways. For example, according to Bird et al. (1993), conflict of interest and
conflict of values stand between research and commercialisation of the research outcomes, such as scientific knowledge. These conflicts delay, re-channel or discourage the commercialisation of research. Bird et al. (1993) have developed some scales to measure these conflicts and have conducted research on determining the impact of these conflicts on entrepreneurial activities and roles of faculty members in a university. Their findings showed a relationship between values-interests and entrepreneurial activity of science and management faculty members. However, they also found differences between science and management faculties in values and orientations existing within the university. That is, there are similarities and differences between these two groups: scientists and entrepreneurs.

Scientists and entrepreneurs might have different aims and values. However, in dealing with the demands placed in the scientific enterprise, labs and multi-disciplinary programmes, scientists may need to know about entrepreneurship and require entrepreneurial skills (Sarasvathy and Venkataraman 2011). Within this purpose, usually, academic institutions and the government facilitate the meeting of these groups. For example, in Ireland, the government supports academia to enable commercialisation of scientific research. The government provides a platform for academics to meet entrepreneurs through the innovation parks and centres at the universities. There are also initiatives through the commercialisation of research funded by the Irish government and the European Commission to enable the converging of these two types of minds to come together for a synergistic relationship. In some situations, entrepreneurial scientists are emerging through these initiatives (Etzkowitz and Leydesdorff 1998; Oliver 2004; Etzkowitz 2008). For example, Maci (2017) introduces Professor Per-Simon Kildal as one of the entrepreneurial scientists due to his discoveries, inventions and the companies that he started. In addition to the platforms, which bring scientists and entrepreneurs together, scientific and entrepreneurial minds can be brought together through incubator programmes. These incubators are multi-disciplinary units/programmes located in academia bringing students together from all disciplines. These units are funded by the state and usually supported by industry (Etzkowitz 2008). These programmes can facilitate the emergence of entrepreneurial scientists.
If there is no entrepreneur or if there is no market, it may be difficult to satisfy people’s needs in this global world. Additionally, if science is to benefit people, it should be transferred to the market for public use. Otherwise, how can people benefit from science? Also, if the scientific outcomes are already transferred to the market why should it not be transferred by scientists, who discovered ideas, developed the knowledge and invented products at the first place, and who knows the possible uses of these scientific outcomes better than many other people? Imagine yourself as a scientist. You made an invention, and you have great ideas about how it can be used for social utility. You have the knowledge and skills to transfer this invention to the market, and you can make some profit by this transfer. Would you attempt to find an entrepreneur to transfer this invention to the market and obtain all the profit by himself/herself or would you actualise this by yourself since you know your product better than anyone else? When the person who developed and transferred the product for public use is the same person, this person is called an entrepreneurial scientist. For example, the physicists who obtained funding from stock options in the semiconductor industry in the late 1970s were called entrepreneurial scientists (Etzkowitz 2008).

Scientists do not have to become entrepreneurs, but having an entrepreneurial mind may increase their innovativeness, creativity, and some other skills, such as decision-making and risk-taking (European Commission 2012a). This is to say that being an entrepreneurial scientist does not mean only working for money and profit. For example, Thomas A. Edison, whose work include the phonograph, the motion picture camera and the long-lasting, practical electric light bulb, is known as a scientist and a businessperson. He founded this so-called “invention factory” in the late 19th century. Edison brought together technologists, scientists, and support staff in a single organisation, to systematically design and patent a series of core technologies and develop spin-off firms to bring them to market (Etzkowitz 2008). Therefore, he can be called an entrepreneurial scientist. This example highlights that even if there is money and business involved in science, it can still be driven by curiosity and shaped by a person’s scientific ethos and social values. As long as awareness of the disadvantages of entrepreneurship is increased as well as its advantages, entrepreneurship can support the creation of socially and economically responsible scientifically literate citizens who contribute to the development of their countries. In the next section, entrepreneurship is explored.
within the science education literature to identify its role in science education better.

2.3.4. Entrepreneurship in Science Education

This section reviews and discusses the literature that refers to entrepreneurship and the scopes of entrepreneurship, such as entrepreneurial scientists, in science education. Research shows that educational institutions have been challenged to prepare industry-ready graduates due to the need to have more global and technological businesses (Achor and Wilfred-Bonse 2013; Hynes et al. 2010). Furthermore, according to Etzkowitz (2008), entrepreneurial training should be a part of general education since new organisation formations are increasing and becoming common in all aspects of life. To situate the place of entrepreneurship within the public-school environment, a body of research has been conducted in entrepreneurship in education worldwide (Amos and Onifade 2013; Gustafsson-Pesonen and Remes 2012; Lepisto and Ronkko 2013; Mattila et al. 2009; Seikkula-Leino et al. 2010, 2015). For example, the European Commission (2012) conducted research to develop national strategies for curricular implications of entrepreneurship education, including learning outcomes on entrepreneurship education in schools throughout Europe. They stated that the primary aim of entrepreneurship education is to support students’ entrepreneurial behaviours by improving students’ knowledge, skills and attitudes. Therefore, they divided knowledge, skills and attitudes into different categories to present specific learning outcomes adopted by European countries for primary and secondary school students.

Seikkula-Leino (2011) researched the implementation process of entrepreneurship education in Finnish schools in 2005 and 2006 and found that although teachers had limited insights on how to implement entrepreneurship into their teaching, they were developing positive attitudes toward entrepreneurship education. However, Mattila et al. (2009) conducted research on teachers’ opinions about entrepreneurship education in Finland and found that teachers, who were teaching different subjects at different education levels, found it difficult to see themselves as part of entrepreneurship education at that time. Lepisto and Ronkko (2013) explored the perceptions of pre-service teachers on entrepreneurship education and
found that although participants did not support teaching entrepreneurship as a core module in primary education, they found enterprising pedagogy useful and inspiring. Likewise, the results of Amos and Onifade (2013) indicated that pre-service teachers perceive entrepreneurship education as very important in pre-service teacher education. There is also the Entrepreneurial School Project which aims to improve the entrepreneurial school environment at primary and secondary/vocational levels in eight countries\(^9\) in Europe (TES 2014-2015). This project found that entrepreneurial learning can be enhanced by adequate teacher training. The project found that while pre- and in-service teachers had a lack of knowledge prior to participation on the project, this knowledge changed over time as their knowledge on entrepreneurship increased. That is, by providing sufficient entrepreneurship knowledge and education, teachers’ perspective may be changed positively through engagement in effective teacher development.

In order to situate the place of entrepreneurship within the public-school environment, a number of international studies have also been conducted in science education (Achor and Wilfred-Bonse 2013; Adeyemo 2009; Amos and Onifade 2013; Annetta et al. 2017; Bacanak 2013; Bikse and Riemere 2013; Buang et al. 2009; Deveci 2016; Deveci and Cepni 2014; Deveci and Seikkula-Leino 2016; Ejilibe 2012; Ezeudu et al. 2013; Jiang et al. 2017; Johson and Amiraly 2017; Kleppe 2002; Lepisto and Ronkko 2013; Nwakaego and Kabiru 2015; Martin et al. 2017). Kleppe (2002) found a need for the integration of the fundamentals of the invention, innovation, and entrepreneurship into all levels of the curriculum by K-12 educators in the USA. The results of Buang et al.’s (2009) study showed that the scientist-entrepreneurs in Malaysia, who owns businesses and have academic qualifications at the same time, were able to integrate entrepreneurial thinking and science process skills in producing their innovative science-based products. Bacanak (2013) indicated that teachers in Turkey have inadequate knowledge of entrepreneurship, and highlighted the necessity of in-service training on improving the teachers’ understanding of entrepreneurship and entrepreneurial skills. Bikse and Riemere (2013) presented that even though graduate science students in Latvia were usually well-qualified to deal with labour market challenges, significant improvements are still required to improve entrepreneurship education. Achor and

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\(^9\) These eight countries are Denmark, Finland, Italy, Norway, Poland, Portugal, Slovakia and the UK.
Wilfred-Bonse (2013) claimed that there is a need for integrating entrepreneurship education into science education and therefore science education college programmes in Nigeria. In the study of Deveci and Seikkula-Leino (2016) in Finland, participants addressed some science topics as more convenient for entrepreneurship education in science classes, such as electrochemical cells or batteries, human biology, the natural environment, statistics and percentages, electricity production, recycling and metals.

The need for and importance of entrepreneurship in science education is evident in science education literature; however, the research examining PSTs’ opinion of the integration of entrepreneurship into science education is rare, and there is very little evidence to show research that has investigated entrepreneurship within the NOS context. Therefore, the current study aims to fill the gap in the literature by examining the relationship between entrepreneurship and NOS in science education and investigating the PSTs’ understanding of entrepreneurship and its curriculum integration. As Sarasvathy and Venkataraman (2011) said, entrepreneurship is not only a career option but also a widespread driver of social change. There may be criticisms of entrepreneurship and neoliberal politics (e.g. Brown 2003; Foucault et al. 2008); however, the curricular relevance is sufficient reason to investigate how to explore these themes in education.

2.4. CONCLUSION

Based on the discussions conducted in Chapter One on the importance of NOS, EOS and entrepreneurship in science education; NOS, EOS and entrepreneurship have been explored further in this chapter. Furthermore, this chapter aided to reveal the relationships between NOS, EOS and entrepreneurship. The theoretical framework of this study was determined as the extended FRA since it is more comprehensive and holistic than the other NOS approaches, and there is a direct reference to the elements of EOS in this framework. The relevance of EOS to NOS was discussed in relation to the “financial systems” in the extended FRA. Furthermore, the place of EOS in science education was presented in the literature. The relevance of entrepreneurship was also discussed based on the literature on entrepreneurship in science education, and its relevance to EOS and scientific enterprise. The significant contribution of this chapter was (1) exploring the role of
EOS and entrepreneurship in NOS and thematising their scopes, (2) informing the science education literature from the formal discipline of EOS and entrepreneurship, and (3) re-defining entrepreneurship in the NOS context.

The literature showed that the role of EOS and entrepreneurship are neglected in NOS for science education, and their educational applications are missing. Furthermore, there is also no framework illustrating how science works in society. Therefore, the next chapter aims to complete these missing dimensions in the literature. The next chapter is one of the main contribution of the current study due to proposing an alternative way to reconceptualise the “financial systems” based on the discussions on the issues involved in it and the advantages of the inclusion of EOS and entrepreneurship in science education. Furthermore, by conceptualising these three concepts (EOS, NOS and entrepreneurship), the SAMI cycle framework is introduced to illustrate how science works in society.
CHAPTER THREE: REVISITING THE “FINANCIAL SYSTEMS” AND PROPOSING THE SAMI CYCLE FRAMEWORK

The importance of the current study was discussed in Chapter One, and the relevant literature was reviewed in detail in Chapter Two. In the first two chapters, the relationship between EOS, entrepreneurship and NOS has emerged. This chapter aims to incorporate, discuss, conceptualise and visualise the literature on EOS, entrepreneurship and NOS. Here, visualisation is significant “due to its potential to create tangible conceptual representations for relatively abstract concepts” (Erduran and Dagher 2014a, p.164). Within this purpose, this chapter:

1. problematises the “financial systems” in the extended FRA
2. proposes the “contemporary social aspects of NOS” as an alternative approach than the “financial systems”
3. proposes a new framework - the SAMI cycle framework, which was developed as part of the current study, as a way of conceptualising EOS, NOS and entrepreneurship
4. argues the contributions and implications of the SAMI cycle framework to science education. This also includes the implications of EOS and entrepreneurship into NOS since the SAMI cycle framework is the conceptualisation of these three concepts (EOS, entrepreneurship, NOS)

3.1. PROBLEMATISING THE “FINANCIAL SYSTEMS” IN THE EXTENDED FRA

Different NOS approaches and the “financial systems” in the extended FRA (one NOS approach) have been introduced in Chapter Two. As mentioned in Chapter Two, improving students’ understanding of EOS is one of the contemporary goals of science education (Erduran and Mugaloglu 2013). The rudimental integration of EOS into NOS has been explicitly initiated by Erduran and Dagher (2014a). They included the “financial systems” as an element of SIS of science in the extended FRA by using economics-related terminology. The FRA approach, with the explicit inclusion of the “financial systems”, is the most comprehensive and informed approach relating to the economic aspect of NOS. However, there are issues emerging related to the “financial systems” in the extended FRA. For example, according to Jiménez-Aleixandre (2015), the features of the SIS of science in NOS is underdeveloped. The primary criticisms posed to “financial systems” relate to:

1. the misleading title
2. its comprehensiveness
3. not being well-informed by the formal discipline of EOS and entrepreneurship
4. structural issues

(Kaya et al. 2018b)

All of these criticisms are discussed below.

3.1.1. The misleading title

Erduran and Dagher (2014a) use the title “financial systems” and wrote a section in their book explaining this system. The terminology used to define and explain “financial systems” is extracted and the EOS-related words and phrases found in this system are presented below:

- Actions of scientists
- Distribution of resources
- Economic forces
- Funding
- Research funding agencies
As seen, this listing of the EOS-related words used in the “financial systems” has EOS content. Erduran and Dagher (2014a) did not intend to provide an exclusive account of EOS, and indeed this category was one of 11 categories in SIS of science. However, from the perspective of the formal discipline of EOS, whilst “finance” is a word related to only money, “economics” also deals with other money-related aspects such as its distribution, its relevance with technology, and its impact on the effectiveness of institutions (Diamond 2008). Thus, from the EOS point of view, the title might mislead the reader.

3.1.2. The comprehensiveness of the “financial systems”

Even though the “financial systems” refers to some of the scopes of EOS, mediation of economic resources for distribution of resources in science and the actions of scientists is presented in the “financial systems” superficially (Kaya et al. 2018b). Commodification and the commercialisation of science, which in the scope of EOS, were introduced but not explained. Furthermore, the system was limited to the funding aspect of EOS and not well informed by the formal discipline.
of EOS. In addition to the discussion on the economic aspect of NOS, an entrepreneurial aspect of NOS can also be argued. The relevance of entrepreneurship to EOS, NOS and science education have been discussed in Section 2.3. Within this context, Erduran and Dagher (2014a) addressed the relationship between science, EOS and entrepreneurship indirectly by stating that whilst the scientific enterprise has been related to military and industry, academic science has been considered as connected to business interests through funding.

Moreover, as mentioned in section 2.3.4, the importance of entrepreneurship in science education has been presented by various researchers who conducted their research in a variety of countries (Bacanak 2013; Bikse and Riemere 2013; Buang et al. 2009; Deveci and Seikkula-Leino 2016; European Commission 2004, 2012; Kleppe 2002; Nwakaego and Kabiru 2015; TES 2014-2015). Even though entrepreneurship is relevant to EOS, NOS and science education (Kaya et al. 2018a, 2018b), it is not presented in the SIS of science, including the “financial systems”. Thus, the “financial systems” is not very comprehensive.

3.1.3. Being informed by EOS and entrepreneurship

Here, the “financial systems” is also criticised by not being well-informed by the formal discipline of EOS and entrepreneurship. As mentioned above relating to the comprehensiveness, the exploration of EOS and entrepreneurship in the NOS content is limited in the SIS of science, particularly in the “financial systems”. This means that this system is not well-informed by the formal discipline of EOS and entrepreneurship. This might result in young people not realising their full potential and being unprepared for the challenges of higher education and career development (Achor and Wilfred-Bonse 2013; Deveci and Cepni 2014; Volkmann et al. 2009).

3.1.4. The structural issues

The “financial systems” is missing a systematic categorisation relating its scope and has structural issues. For example, Erduran and Dagher (2014a) mention the commodification and commercialisation of science but neither explore its content nor mention it within the scope of EOS. Likewise, funding is discussed in the
system but where and how funding can be provided are not clarified, and “funding” is not presented as a category or theme within the system. Thus, there are structural issues, such as the categorisation and clarification of the content of the “financial systems”.

Overall, firstly, the title -financial systems- should be changed to incorporate and embrace its content better. Secondly, a more holistic and comprehensive perspective should be adopted in the system, which might involve the inclusion of, in this instance, EOS and entrepreneurship. Thirdly, the system should be informed by the formal disciplines of EOS and entrepreneurship. Fourthly, the system should be structured by categorising and clarifying the content systematically. Thus, in the next section, “contemporary social aspects of NOS” is proposed as an alternative way to “financial systems” to overcome the related concerns.

3.2. RECONCEPTUALISING THE “FINANCIAL SYSTEMS”: CONTEMPORARY SOCIAL ASPECTS OF NOS

Concerns relating to aspects of the “financial systems” has been discussed in the previous section. In response to these issues, this section proposes “contemporary social aspects of NOS” as an alternative way to enrich NOS through the inclusion of EOS and entrepreneurship. This section argues the proposed changes as follows:

1. Changing the name of the “financial systems” to “economics of science in nature of science” and include it in the social aspects of NOS.

2. Structuring “economics of science in nature of science” by informing it from the formal discipline of EOS. Within this context, EOS in NOS is structured under three themes, namely science and scientists in industry, funding of research at academic institutions, and commodification and commercialisation of science.

3. Including entrepreneurship in the social aspects of NOS with the title of “entrepreneurship in nature of science”.

4. Structuring “entrepreneurship in nature of science” by informing it from the formal discipline of entrepreneurship. Within this context, entrepreneurship
in NOS is structured under three main themes, namely career stage (job opportunities), entrepreneurship in science and entrepreneurial scientists.

5. Proposing “contemporary social aspects of NOS” as an alternative way of the “financial systems” with EOS and entrepreneurship being the components of the “contemporary social aspects of NOS”.

How NOS and science education are enriched through the inclusion of “contemporary social aspects of NOS” is discussed in this section.

Figure 3-1 was developed to summarise the proposed changes in the “financial systems” to reconceptualise it as “the contemporary social aspects of NOS”. Figure 3-1 also illustrates the place of the “contemporary social aspects of NOS” in the extended FRA.
Figure 3-1: The place of contemporary social aspects of NOS in the extended FRA

The proposed changes are argued in the following sections.
3.2.1. Changing the name of the “financial systems” and increasing its comprehensiveness

The current study proposes to change the name of the “financial systems” to “economics of science in nature of science” and include it in the social aspects of NOS. The reason for this is discussed in the previous sections. Briefly, it can be said that the inclusion of “economics” in the title is viewed as more comprehensive than “finance”, and it also includes relevant aspects previously included in the “financial systems”, such as distribution, the behaviour of scientists and money. Additionally, based on the discussion in Section 2.2, it can be said that the characterisation of science is related to the economic features of science. The inclusion of EOS is critical for creating responsible citizens who are scientifically literate, sensitive to socio-economic issues and who are aware of how some of their taxes are used for funding in scientific research (Erduran and Dagher 2014a). Developing awareness in students of how funding and grants affect the operation of science and that the development of scientific enterprise relies on the scientific patents and knowledge are also significant (Erduran and Mugaloglu 2013). Another rationale can be that the countries need scientifically literate responsible citizens who are concerned with their role in the social and economic development of their country (Kelly 2007).

EOS in science education provides more than just economic benefits. For example, teaching and learning about the economic aspect of science can provide students and teachers with a greater understanding of cross-curricular links of science, making science more relatable to students’ everyday life and aiding students to realise the everyday applications of science (Kaya et al. 2018b). Moreover, as discussed in Chapter One, EOS can also bring an ethical perspective to science, and this could improve students’ perspective (Irzik 2007, 2013; Krimsky 2004; Resnik and Elliott 2013; Van Norman and Eisenkot 2017a, 2017b). As seen, the inclusion of EOS into NOS can provide broader benefits than the economic well-being perspective. Thus, it is proposed to change “financial systems” to “economics of science in nature of science” (EOS in NOS) to make this system more holistic and comprehensive, to overcome title – content discrepancy and to clarify the role of EOS in the social aspects of NOS.
3.2.2. Structuring “economics of science in nature of science” by informing it from the formal discipline of EOS

With regards to structuring “economics of science in nature of science”, this new social aspect of NOS – EOS in NOS – was informed by the formal discipline of EOS. In this sense, the context drawn from EOS literature in Section 2.2 presented three main themes, namely science and scientists in industry, funding of research at academic institutions, and commodification and commercialisation of science. These themes are also conspicuous in the science education literature (Erduran and Dagher 2014a; Erduran and Mugaloglu 2013; Irzik 2013; Kaya et al. 2018b). Therefore, the EOS in NOS is structured under three themes, namely science and scientists in industry, funding of research at academic institutions, and commodification and commercialisation of science by providing the information from the formal discipline of EOS.

3.2.3. Including entrepreneurship in the social aspects of NOS

The current study proposes to include entrepreneurship in the social aspects of NOS with the title of “entrepreneurship in NOS”. Concerning the inclusion of entrepreneurship in NOS, as mentioned in Chapter Two, NOS already accepts the feature of science as an enterprise. The scientific enterprise is discussed within the context of entrepreneurship.

Furthermore, as advocated by Driver et al. (1996), one persuasive justification why contemporary aspects matter is that:

science demands considerable resources from the wider society, justifying these demands on grounds which range from the utilitarian (in the case of much medical research) to the cultural (in the cases of astronomy and high-energy particle physics). Public funding on the scale involved requires that the public understand and, in the main, share the aims and aspirations of the scientific enterprise and understand how resources are used on society’s behalf.

(Driver et al. 1996, p.19)
As seen in this quote, the role of scientific enterprise came up again. Moreover, Kaya et al. (2018b) also claim that entrepreneurship is of relevance to NOS. There are various rationales for involving entrepreneurship in NOS and science education. For instance, integration of entrepreneurship into NOS in science education can contribute to:

- create new job opportunities (Achor and Wilfred-BONSE 2013)
- increase students’ awareness of economics-related issues (Deveci 2016)
- teach students how scientific knowledge and products become available in the market for public use (Deveci and Cepni 2014)
- teach students how funding and grants affect the operation of science
- contribute to the social and economic development of a country (Amos and Onifade 2013)
- create industry-ready graduates to satisfy the need in the global world (Hynes et al. 2010)
- create scientifically literate responsible citizens who are concerned with their role in countries’ social and economic development (Kelly 2007).

Thus, the inclusion of entrepreneurship into NOS is also proposed due to its relevance and potential benefits to NOS and science education and the need for industry-ready graduates.

3.2.4. Structuring “entrepreneurship in nature of science” by informing it from the formal discipline of entrepreneurship

Concerning the structure of entrepreneurship in NOS, this new social aspect of NOS – entrepreneurship in NOS - was informed by the formal discipline of entrepreneurship. In this sense, the context drawn from entrepreneurship literature in Section 2.3 presented three main themes, namely career stage (job opportunities), entrepreneurship in science and entrepreneurial scientists. These themes are also conspicuous in the science education literature (Achor and Wilfred-BONSE 2013; Deveci 2016; Ejilibe 2012; Erduran and Dagher 2014a; Kaya et al. 2018b; Martin et al. 2017). Thus, entrepreneurship in NOS as one of the
contemporary social aspects of NOS is structured under three themes, namely \textit{career stage (job opportunities), entrepreneurship in science} and \textit{entrepreneurial scientists} by providing the information from the formal discipline of entrepreneurship.

3.2.5. Proposing “contemporary social aspects of NOS” as an alternative way of the “financial systems”

Even though some contemporary accounts of science, such as EOS and entrepreneurship, are not the core characterisation of science these contemporary accounts are of importance. Within this context, according to Driver et al. (1996):

\begin{quote}
\begin{center}
\textit{an understanding of contemporary science is also important. This would involve knowing about the institutional framework and processes of science, its organisation into disciplines, sub-disciplines, research groups and so on, its methods of funding, its systems of recognition and reward.}
\end{center}
\end{quote}

(Driver et al. 1996, p.19)

Funding, recognition and reward as emphasised in the above quote are some of the aspects of EOS. However, EOS and entrepreneurship related contemporary aspects of science are overlooked in the SIS of science. This is evident in the fact that research highlighting the contemporary aspects in NOS is rare as discussed in Chapter One and Chapter Two. Furthermore, science is a public good and therefore, science education should support the freedom of science. Likewise, Kaya et al. (2018b) believe that science should be free from social, economic and political forces and done in the pursuit of knowledge, and science education should support the ideal of the autonomy of science.

However, emancipating science from social, economic and political forces cannot be achieved by ignoring the place of economics and entrepreneurship in science. Students should be educated by increasing their awareness of the advantages and disadvantages of EOS and entrepreneurship as well as the other aspects of science as an SIS. Therefore, due to the criticisms of the “financial systems”, an alternative way – “contemporary social aspects of NOS” is proposed to enrich NOS by the inclusion of EOS and entrepreneurship. The aim of this inclusion is not to trivialise the other aspects of SIS of science, but to bring a more holistic and comprehensive
perspective to NOS by proposing to embrace its contemporary social aspects as part of the social aspects of SIS of science. The reason for calling EOS and entrepreneurship as “contemporary social aspects” rather than social aspects is that even though these characteristics are not in the essence of social aspects of science, the global world requires and engenders these characteristics and their implementation in education (Anderson et al. 2017; Bakhshi et al. 2017; DES 2016; Volkmann et al. 2009). That is, the current requirements point to the need for graduates with economic understanding and entrepreneurial perspective (Achor and Wilfred-Bonse 2013; Hynes et al. 2010). As the requirements change, the components of the contemporary social aspects can change. For example, if engineering is one of the requirements at the time, it can be included in the contemporary social aspects of NOS.

When proposing the “contemporary social aspects of NOS”, the literature from the formal discipline of EOS and entrepreneurship was utilised. The relationship between EOS, entrepreneurship and NOS was clarified and “contemporary social aspects of NOS” was offered as a new comprehensive and holistic way in this section. The discussion conducted in this section also informs the research design process in the latter half of the current study. In Chapter One and Chapter Two, the state, academia, market and industry are mentioned repeatedly within the context of EOS, entrepreneurship and NOS. Based on what has been presented in the first three chapters, some changes emerged in the SIS of science. The structure of SIS of science is presented in Figure 3-2 before and after the changes (See Appendix 2 and Appendix 3 for larger figures).

The components of the SIS of science before and after the changes are numbered\(^{10}\) in Figure 3-2. For example, “professional activities” is numbered “1” before the changes and numbered “1.1” after the changes. Starting with the component 1 in Figure 3-2, grant applications are removed from “professional activities” (1) and included in “EOS in NOS” in the “contemporary social aspects of NOS” (7.1) after the changes. This is because the grant application is one of the ways of acquiring funding (Kaya et al. 2018b). Academic proposal writing is added to “professional activities” (1.1) after the changes due to the scope of professional activities since

\(^{10}\) 1 and 1.1: Professional activities, 2 and 2.1: Scientific ethos, 3 and 3.1: Social values, 4 and 4.1: Social certification and dissemination, 5 and 5.1: Social organisations and interactions, 6 and 6.1: Political power structures, 7: Financial systems, 7.1: Contemporary social aspects of NOS
this is required when scientists are applying for a grant. No changes are made to components 2, 3 and 4.

Figure 3-2: Science as a social-institutional system before and after the changes

Career stage is moved from “social organisations and interactions” (5) to “entrepreneurship in NOS” in the “contemporary social aspects of NOS” (7.1) after the changes due to the fact that the career development and providing job opportunities are in the scope of entrepreneurship (Birdthistle et al. 2007; Bruyat and Julien 2001). Establishing relationships in “social organisations and interactions” (5) is extended and involved as networking (5.1) after the changes. The relationship between State-Academia-Market-Industry is added as a category to “social organisations and interactions” (5.1) after the changes. The reason for this is that bilateral relations between state/government, university and industry already emerges in “social organisations and interactions” in the extended FRA (Erduran and Dagher 2014a). Moreover, with the inclusion of “contemporary social aspects of NOS” to social aspects of NOS, the relationship between state/government, academia, market and industry came out. The relationship between state/government and science is added to “political power structures” (6.1.) after the changes. The “financial systems” (7) is removed, and “contemporary social aspects of science” (7.1) is added as another category and divided into two categories: “EOS in NOS” and “entrepreneurship in NOS” after the changes. These two categories are sub-categorised based on the literature in Section 2.2 and Section
Thus, Figure 3-3 illustrates the SIS of science with the inclusion of proposed themes and organisations for the SIS of science in the current study.

Figure 3-3: Reconceptualised social-institutional system of science based on Erduran and Dagher (2014a, p.151)

What has been presented so far is summarised in Figure 3-3 adapted from the figure developed by Erduran and Dagher (2014a) which was presented in Figure 2-3. However, the relationship between the state, academia, market and industry, which emerged in Chapter One and Chapter Two, is still not clear. Furthermore, as mentioned previously in Section 1.2 and 2.1, NOS aims to understand how science works and the current study focuses on the social aspect of NOS. Therefore, the current study also aims to understand how science works in society. However, this question is still not answered. There are still unanswered questions; for example, how can we explain how science works in society? What would be the relationships between the state, academia, industry and the market? Why is this relationship significant for school science? Thus, in the next section, the SAMI cycle framework is developed to answer these questions by conceptualising NOS, EOS and entrepreneurship, and illustrating how science works in society. This framework is
proposed to be used in the science classroom to teach how science works in society. At the end of the chapter, a concluding paragraph is given.

### 3.3. HOW DOES SCIENCE WORK IN SOCIETY?: SAMI CYCLE FRAMEWORK

Thus far, NOS, EOS and entrepreneurship have been presented, and their relationship has been explored. Within this context, the role of state/government, academia, market and industry became evident in the NOS, EOS and entrepreneurship literature. For example, the *State/government* was emphasised in “political power structures” in the extended FRA (Erduran and Dagher 2014a) and referred to in EOS and entrepreneurship context repeatedly. *Academia* is evident in all literature since the literature emerged due to the research and publications that academics have conducted. The *Market* is majorly referred to in EOS and entrepreneurship literature (e.g. Hisrich and Peters 2002). The *Industry* is emphasised in “financial systems” in NOS (Erduran and Dagher 2014a), in science and scientists in industry in EOS (e.g. Stephan 1996) and entrepreneurship (e.g. Burguer-Helmchen 2012). Additionally, the role of the market and industry is also presented in the EOS in NOS, and entrepreneurship in NOS within the context of “contemporary social aspects of NOS” in the previous section.

Thus, this section proposes a framework by bringing together these concepts (state/government, academia, market and industry) that has emerged from the current study and is called the *SAMI cycle framework*. This framework conceptualises NOS, EOS and entrepreneurship, elucidates the relationship between the State/government, Academia, Market and Industry, and visualises how science works in society. When conceptualising the NOS, EOS and entrepreneurship, the SAMI cycle framework brings the components of SIS of science (Erduran and Dagher 2014a) together with the aspects of EOS and entrepreneurship, such as the *science and scientists in industry* and entrepreneurs. The SAMI cycle framework is implemented into pre-service science teacher education (PSTE) in the latter half of the current study. In the following subsections (Section 3.3.1 and 3.3.2), how the SAMI cycle framework has been
developed is introduced, and the contributions of this framework to science education is justified respectively.

3.3.1. The Development of the SAMI Cycle Framework

As mentioned previously, the SAMI cycle framework has evolved from the analysis of the literature, and it is one of the key contributions of the current study. This section presents how this framework has evolved. The SAMI cycle framework has been developed in three stages: (1) NOS as a foundation, (2) EOS to build upon the process and (3) entrepreneurship to complete the process. Before starting to explore these stages, what is meant by industry and market should be clarified. In this framework, while industry refers to a sector of the economy, in which firms make a group of related products, a market refers to a place or institution in which buyers and sellers meet (Black et al. 2009). Therefore, the industry refers to the production and the market refers to where the products are sold or the targeted group to sell the product (Kaya et al. 2018b). The SAMI cycle framework has been implemented in PSTE as part of an intervention and it has not yet been used in a wider implementation.

3.3.1.1. Stage 1: NOS as a Foundation

The first draft of the SAMI cycle framework emerged at the end of this stage and is presented in Figure 3-4. The SIS of science in the extended FRA (Erduran and Dagher 2014a) informed this stage since the extended FRA is the theoretical framework of the current study. NOS aims to understand how science works (Allchin 2011; Erduran and Dagher 2014a, 2014b; Irzik and Nola 2014; Martins and Ryder 2015), and the current study targets the social aspects of NOS. Therefore, firstly, the process of how science works in society was explored.
As mentioned in Section 2.1.2.1, the SIS of science is comprised of seven components, namely professional activities, scientific ethos, social certification and dissemination, social values of science, social organisations and interactions, political power structures and financial systems. Here, the elements of the SAMI cycle framework, which are state/government, academia, market and industry, are explored within the components of the SIS of science and illustrated with the colour yellow font in Figure 3-4. While explaining the SAMI cycle framework in the context of the SIS of science, the process was started by scientists in Figure 3-4 and moved clockwise. Beginning with the scientists, in the SIS of science, “social organisations and interactions” and “financial systems” were referring to academic institutions and industrial places as scientists’ workplaces. This is illustrated in Figure 3-4 with an arrow going from scientists to academia and industry. However, the relationship between academia and industry was a transparent colour since the relationship was vague and incomplete.
Continuing with the *academia* and *industry*, the activities that scientists are involved in their workplaces, such as conducting research, and that they perform anywhere related to their work, such as attending conferences, emerged in “professional activities”. These scientific activities are referred to in Figure 3-4 as conducting basic and/or applied research, producing scientific knowledge, acquiring funding and performing professional activities, such as attending conferences and publishing. Going back to *scientists*, the outcomes of the scientific activities, such as conducting research can be again used by *scientists*. Here, “social certification and dissemination” indicated that research results are certified by the scientific community and disseminated to the scientific community or to the others (e.g. public), which is represented by an arrow going out from scientific activities, such as conducting research, back to *scientists*. The role of the *state/government* on science was referred to in “political power structures”. Thus, the precursors of the organisation of how science works in society, which illustrates the relationship between state, academia and industry, also emerged here.

Moreover, “financial systems” identified to the role of government as providing funding. The government may influence the academia, industry, scientific activities, scientific ethos and more; therefore, state/government was visualised in Figure 3-4 within the *society* without having any direct connections with other elements in the framework. Science and society have their ethical and moral regulations, and the scientific knowledge is shared and used for social utility. The social utility and moral and ethical dimensions were referred to in “social values of science” and “scientific ethos”. Due to their importance for society, “social values of science” and “scientific ethos” were represented at the core of the framework. All these mentioned points are involved in the social-institutional system of science, and this framework aims to explain how science works in society; therefore, society was represented by a large circle involving the elements mentioned at Stage 1.

3.3.1.2. Stage 2: EOS to Build upon the Process

The second draft of the SAMI cycle framework emerged at the end of this stage and is presented in Figure 3-5. Although the relationship between state/government, academia and industry started to emerge this relationship was
not well informed and comprehensive. Furthermore, as seen in Figure 3-4, the colour of the relationship between the academia and industry was left transparent since this relationship was vague and incomplete. Therefore, the EOS literature was utilised to inform the framework during the second stage of developing the SAMI cycle framework. EOS literature was viewed as important since all the process from the graduation of scientists to the supply and demand between the academia and industry falls within the scope of the EOS (Diamond 2008; Erduran and Mugaloglu 2013; Irzik 2007, 2013; Mirowski and Sent 2002; Radder 2010; Stephan 1996). Notably, the scopes of EOS presented in Section 2.2.1, which are *science and scientists in the industry, funding of research at academic institutions* and *commodification and commercialisation of science*, informed the second stage of the SAMI cycle framework and illustrated with the colour yellow font in Figure 3-5. Therefore, the following changes/additions were made to the framework:

1. The relationship between the academia and industry was clarified, and the transparency in colour was removed.
2. Producing products was added to scientific activities.
3. Internal dissemination in academia and industry was represented by two cyclic arrows.
4. The market became involved in the process.
5. The relationship between the market and scientists were represented by a two-way arrow.

Concerning the academia-industry relationship, *science and scientists in industry*, the first scope of EOS (See Section 2.2.1), clarified the relationship between academia and industry, which was underdeveloped in Stage 1. By the clarification of the relationship, the transparency in colour between academia and industry was removed in Stage 2. This scope of EOS also informed the scientists’ workplaces and the activities that they perform. Within this context, cooperation and collaboration between academia and industry were explored (Etzkowitz 2008; Mirowski and Sent 2002; Stephan 1996; Vallas and Kleinman 2007; Van Norman and Eisenkot 2017a, 2017b). The supply and demand relationship between academia and the industry was identified (Stephan 1996; Romer 2001). It has been mentioned that scientists may work in academic institutions or industrial places, or in both at the same time (Irzik 2007, 2013; Mirowski and Sent 2002; Stephan 1996).
The second scope of EOS is the *funding of research at academic institutions* (See Section 2.2.1). According to this scope of EOS, scientists can acquire funding through the scientists’ workplaces or apply for a grant to funding agencies (Kaya et al. 2018b). This funding can be provided for scientific research by the government, industry and/or business (Carter 2008; Erduran and Mugalôlu 2013; Irzik 2007; Radder 2010; Stephan 1996). However, the financial relationship between government, industry and/or business and academia may affect the credibility of research (Resnik and Elliott 2013; Van Norman and Eisenkot 2017a, 2017b). The credibility of the research is relevant to scientists’ ethos and values; thus, it is included in “scientific ethos” at the core of the framework. Regarding producing scientific products as part of scientific activities, *commodification and commercialisation of science*, which is the third scope of EOS (See Section 2.2.1), indicated how the results of scientific knowledge became marketable commodities by the mechanisms of intellectual property (Irzik 2007, 2013; Oliver 2004; Radder 2010). Therefore, the development of scientific products/goods emerged here and
added to the framework at this stage. This and the following new additions to the framework are highlighted in red in Figure 3-5 as the contributions of EOS to explain how science works in society.

Concerning the internal dissemination in academia and industry, the scientific knowledge and/or products are sometimes used in the field that they are produced. That is, some scientific research is driven by curiosity alone with no marketable end within sight. This is presented in the figure by addition of an arrow circulating within the “Academia” and “Industry”. Concerning the involvement of the market in the process of the operation of science in society, sometimes the scientific knowledge and/or products are transferred to the market. This is represented in the figure by the inclusion of arrow going out of “Academia” and “Industry” to the market.

With regards to the relationship between the market and scientists, the role of the market and the two-way relationship between scientists and the market in the process started to appear at this stage. However, they were neither clearly determined, nor well informed. Therefore, in Figure 3-5, the relationship between scientists and the market, and the role of the market were highlighted in red, but the colour was left transparent since the relationship was vague and incomplete at Stage 2.

3.3.1.3. Stage 3: Entrepreneurship to Complete the Process

The final version of the SAMI cycle framework emerged at the end of this stage and is presented in Figure 3-6. Even though the market started to emerge in Stage 2, the role of the market and its relationship with state/government, academia and industry were not fully informed, and it was incomplete. Therefore, the entrepreneurship literature was utilised in this stage to complete the missing knowledge in the framework. Mainly, the broader definitions of entrepreneurship (See Table 2.6), and emerging areas of entrepreneurship in NOS, such as entrepreneurship in science and entrepreneurial scientists (See Section 2.3 and 3.2), informed the framework and illustrated with the colour yellow font in Figure 3-6. Additions made at this stage were related to the market. To finalise the process of how science operates in society, the missing knowledge was examined at this stage, which included how the scientific knowledge is utilised in the market and how the
scientific products are transferred to the market. Within this context, the following changes/additions were made to the framework:

1. How the outcomes of the scientific activities are transferred to the market is added.
2. What is involved in the market is identified.
3. The relationship between scientists and the market is clarified.
4. Different state politics, such as the welfare state, are illustrated.

Regarding the transfer of the outcomes of the scientific activities to the market, entrepreneurship literature indicated that entrepreneurs transfer the scientific knowledge and products into the market in the form of goods and services (Birdthistle 2004; Hisrich and Peters 2002; Hynes et al. 2010). Thus, this transfer of knowledge, goods, and/or services are added to the arrow going out of scientific activities to the market in Figure 3-6. Relating what is involved in the market, the role of entrepreneurs in the market was identified as buyers or sellers (Hisrich and Peters 2002), and some examples of buyers and sellers were found, such as consumers and companies. Companies were referred to in both EOS and entrepreneurship literature. The relationship and supply and demand between buyers and sellers were also determined (Burguer-Helmchen 2012; Sarasvathy and Venkataraman 2011) and represented with the inclusion of cyclical arrows in the market. Therefore, in Figure 3-6, the market represented buyers and sellers, and their relationship within the market.

Concerning the science-market relationship, a two-way relationship was included in Figure 3-6 between the scientists and the market. This relationship was created due to the demand in the market (Armstrong and Tomes 2010; Bird et al. 1993; Bruyat and Julien 2001; Johnston and Edwards 1987; Mueller 2006; Oliver 2004; Sanders 2007). That is, entrepreneurs take a further need as an opportunity if this need cannot be supplied within the market (Shane and Venkataraman 2000). Also, the entrepreneur may inform the scientists working in academia and/or industry about the need in the market. Scientists can also realise the need in the market themselves and conduct basic or applied research on the issue. Therefore, the relationship between market and scientists is represented by a two-way arrow.
With regards to the different state politics and the role of the state/government, the state/government also has an impact on entrepreneurs. The government can decide about the market requirements and therefore shape the market. Furthermore, the role of the state/government is also critical because the state/government ensures the existence of free and effective markets. Once markets are left alone, they most likely become inefficient and unfree (Foucault et al. 2008; Polanyi 1957). State/government does not always interact with industry and academia but it can affect the whole process, and it is fundamental to society. That is, the state/government can influence or be involved in different parts of this process at different times. Thus, government/state is represented within the society but on the side. State politics also affect the size of production, distribution, scientists’ scientific ethos and social values, and so on. That is, different state politics, such as the welfare state and the neo-liberal state, affect academia, market, industry and
their relationship in society. State/government affects the funding, grant system, and therefore the market type and market economy. For example, a welfare state has a perspective of equality of opportunity, unbiased distribution of wealth, and public responsibility to support the people who need aid (Kuhlmann 2018).

Finally, as mentioned previously, society is presented with a large circle because all the process occurs within society and this framework visualises how science works in society. There can be different societies with different state politics, and the SAMI cycle framework can be adapted to different societies. Therefore, the development of the SAMI Cycle framework was completed based on the literature. Additionally, to increase the validity of the representation, the visual of the SAMI Cycle framework was provided to some lecturers and researchers with different subjects and their interpretation of the visual was asked. Given the similar explanations of the process increased the validity of the visual.

Even though the relationship between the university, industry and the government has been discussed by various researchers (Etzkowitz 2008; Etzkowitz and Leydesdorff 2000; Mueller 2006), the SAMI cycle framework is different than the others. These differences are identified as follows:

1. In the SAMI cycle framework, social aspects of NOS are included, such as professional activities, social values and scientific ethos.
2. To be more representative, the SAMI cycle framework focuses on academia instead of university. The reason for this is that in some countries, such as Ireland and the UK, universities and colleges are the same thing, and also there are some academic research centres.
3. The SAMI cycle framework can be adaptable to different state politics, such as neoliberal state or welfare state.
4. The market and society are added to the SAMI cycle framework since they have a role in the operation of science.
5. The relationship between state/government, academia, market and industry is visualised and explained how science works in society.
6. The educational applications of the SAMI cycle framework have also been developed and applied at PSTE (See Chapter Four to Chapter Six). Therefore, this framework has an educational account.
The SAMI cycle framework demonstrates a nuanced, profound way of comprehending how scientists work within and across social and scientific institutions, and how they interact with each other and with stakeholders, such as funding agents and entrepreneurs. The current study aimed to expose PSTs to the concepts of the contemporary social aspects of NOS and the SAMI cycle framework, which is presented in the latter half of the current study. To expose the PSTs to these concepts educational applications of these concepts were developed, which became an additional contribution of the current study. In the next section, the relevance and benefits of the SAMI cycle framework to science education are explored.

3.3.2. Justifying the Contributions and Implications of the SAMI Cycle Framework to Science Education

This section justifies the relevance and contributions of the SAMI cycle framework, including the “contemporary social aspects of NOS” to science education. Furthermore, the possible implications of the SAMI cycle framework are argued to enrich the classroom applications. These possible implications also include the implications of EOS and entrepreneurship into NOS since the SAMI cycle framework is the conceptualisation of these three concepts (EOS, entrepreneurship, NOS). Within this context, two primary aspects are considered to justify the contributions of this framework: integration to the syllabus to improve second or third-level students’ and teachers’ understanding holistically and to improve the economy and society. This is followed by introducing the implications of the framework for science classrooms.

3.3.2.1. Improving Students’ and Teachers’ Holistic Understanding of Science through the SAMI Cycle Framework

This section discusses the integration of the SAMI cycle framework to improve the second or third-level students’ and teachers’ understanding more holistically. Within this context, the SAMI cycle framework provides a practical and visual tool aiming to enhance not only the comprehensive understanding of the social aspects of NOS and how science works in society, but also students’ and teachers’
awareness of the relationship between state, academia, industry and the market (Kaya et al. 2018b).

Most countries mention the importance of science in society and NOS (DES 2015; NRC 1996; Yarime et al. 2012). Moreover, as highlighted earlier, economics and entrepreneurship are amongst the most coveted skills in education in many countries. For example, Ireland included “Science in Society” in the JCSS as one of the NOS strands; and this strand has the potential to embrace the social aspects of NOS and the SAMI cycle framework. There is also a reference to the entrepreneurial skills and economics in the 24 Statements of Learning in the Junior Cycle Specification (DES 2004, 2015). Likewise, entrepreneurship is referred to as one of the life skills, and the importance of economics has been emphasised, for example, in the Turkish Science Curriculum (Board of Education and Discipline 2013). Some other countries, such as the USA, Sweden and Finland, also highlight the importance of entrepreneurship and the economic aspect of science (Deveci and Seikkula-Leino 2016; European Commission 2008; Johson and Amiraly 2017; Martin et al. 2017).

Additionally, NOS is to understand how science works, and the current study is based on social aspects of NOS and how science works in society. Due to the pertinence of how science works in society, EOS and entrepreneurship to NOS and science education, the SAMI cycle framework is of relevance to NOS and science education. Furthermore, because of including social aspects of NOS, it is, in particular, relevant to the JCSS in Ireland. Thus, it is beneficial to briefly elucidate how the social aspects of NOS (Erduran and Dagher 2014a, 2014b), which is emphasised in the SAMI cycle framework, might contribute to science education, in particular to the JCSS.

As discussed in Section 3.3.1.1, the SAMI cycle framework includes the seven components of the SIS of science (Erduran and Dagher 2014a). Applying these components of the SIS of science in science classes may contribute to students’ knowledge and skills (Kaya and Erduran 2016). For example, applying similar “professional activities” to scientists’ activities, students may improve their communicating skills and their management of information and thinking skills, and therefore they can make considered decisions. Due to the inclusion of the
“scientific ethos” and “social values of science”, this framework also integrates an “ethical dimension” to our understanding. Thus, students might realise that there are certain ethical considerations and scientific ethos/norms forming, evaluating and supporting science (Erduran and Dagher 2014a; Irzik and Nola 2014). Therefore, they can be more sensitive to these ethical, social and scientific considerations.

By improving students’ understanding of “social certification and dissemination” in science, students can learn about which information to trust and the importance of sharing information. Having knowledge of “social organisations and interactions” may support students to enhance their understanding that science does not only operate in academia and scientific research centres, but also operates in society. By making students realise “political power structures” in science, students’ awareness of how scientific knowledge is generated, used and sometimes abused is increased. Therefore, students’ can realise the results of poor uses of science and learn about taking responsibilities for its uses. Although SIS of science includes the economic aspect of science within “financial systems”, economic aspect is involved here within “EOS in NOS”. By increasing students’ understanding of the role of EOS in NOS, students can realise that economic factors and political agencies impact on science. Furthermore, students can realise that in the future some of their taxes are used to fund and support scientific research. Therefore, components of SIS of science can contribute to improving some key skills of the Junior Cycle Specification (Dagher and Erduran 2016, 2017).

“Entrepreneurship in NOS” is also included in “contemporary social aspects of NOS” in the current study and informed the SAMI cycle framework. Teaching science in an entrepreneurial context, as well as its scientific context, can support students to realise different job opportunities (Achor and Wilfred-Bonse 2013), take responsibility for their lives (Birdthistle et al. 2007), and understand the importance of entrepreneurship in the process of making scientific knowledge and/or products available for public or private use in society (Deveci and Cepni 2014). By learning about the social aspects of NOS including EOS and entrepreneurship, some of the Key Skills in the Junior Cycle Specification in Ireland can also be improved, such as being creative, being literate, being numerate, communicating, managing information and thinking, managing myself and
working with others (DES 2015; NCCA 2005). By improving students’ awareness of these social aspects, students comprehend science in its social context (Allchin 2011). Therefore, they can realise that scientists benefit society with more than conducting scientific research. Additionally, teaching these social aspects of NOS could also support students to make considerate decisions and contribute to make the world a better place. Overall, due to its inclusion of all elements of the SIS of science and the elements of contemporary aspects of NOS, the SAMI cycle framework is a powerful visual tool to represent how science works in society. Because the SAMI cycle framework is the conceptualisation of NOS, EOS and entrepreneurship, benefits of NOS, EOS and entrepreneurship in science education are also reflected in this framework.

This framework embraces a holistic and comprehensive view of the subject matter and visualises the relationship between concepts by breaking down the subject boundaries. By doing so, the awareness of the cross-curricular links can also be improved. Furthermore, making students realise the relationship between state/government, academia, market and industry can make science more relatable to everyday life. Kaya et al. (2018b) also believe that when teaching how science works in society, the SAMI cycle framework could help students to realise the everyday applications of science and how a scientific process operates moving from academia to the market rather than only focusing on how science operates within academia. Therefore, the SAMI cycle framework provides a more holistic understanding of the second or third-level students and teachers as well as providing an understanding of the complex relationships and cross-curricular links between different subjects.

3.3.2.2. Contributing to the development of the economy and society

This section discusses the integration of the SAMI cycle framework to contribute the development of economy and society. The SAMI cycle framework may affect the economy and society due to its possible impacts on students’ understanding. The SAMI cycle framework may contribute to increasing students’ awareness of self-employment as a career option. Thus, students may start realising the possibility of starting their own business. This is highlighted in the
Entrepreneurship literature in Section 2.3. Creating new job opportunities (Achor and Wilfred-Bonse 2013; Birdthistle et al. 2007; Bruyat and Julien 2001), teaching students how scientific knowledge and products become available in the market for public use (Deveci and Cepni 2014) and creating industry-ready graduates to satisfy the need in the global world (Hynes et al. 2010) can also be seen as an investment to the future of the countries’ wealth. A country’s economy needs enterprising graduates who can take control of their own lives (Birdthistle et al. 2007) and who have scientific literacy. The economic well-being of a nation and scientific literacy can be achieved by improving the awareness of students on current issues like social and economic issues in NOS and science education (Allchin 2011; Erduran and Dagher 2014a; Erduran and Mugaloglu 2013; Kaya and Erduran 2016; Kelly 2007). Thereby the social and economic development of a country could be maintained (Amos and Onifade 2013).

Entrepreneurship and EOS have a significant role in the social and economic development of countries (Etzkowitz 2008), and therefore many countries pay particular attention to entrepreneurship and EOS in science and education. For instance, there are opportunities in the USA to apply for federally sponsored research by the National Science Foundation (NSF) and STEM grants provided by private businesses. Entrepreneurship has the potential of:

changing the way we live, work and play, and transforming the courses of the careers we build, the shapes of communities we live in, and the evolution of the socio-political and economic systems we are part of.

(Sarasvathy and Venkataraman 2011, p.115)

Thus, due to the impact of entrepreneurship on the social and economic development of countries (Etzkowitz 2008; Saravatsky and Venkataraman 2011) and the inclusion of entrepreneurship in the SAMI cycle framework, this framework could contribute to increasing the wealth of the countries. Additionally, the National Science Education Standards (NRC 1996) recommended that students must have the opportunity to experience science authentically and free of misconceptions and idealisations about the nature of the scientific enterprise. Teaching these social aspects of NOS is of importance to support students to make considerate decisions and contribute to make the world a better place. In this sense, learning about the nature of scientific enterprise may contribute to developing
responsible citizens who are sensitive about scientific issues (Erduran and Dagher 2014a, 2014b; Erduran and Mugaloglu 2013) and who are concerned with their role in countries’ social and economic development (Kelly 2007).

Overall, the SAMI cycle framework is of relevance to NOS and science education due to the pertinence of how science operates in society, EOS and entrepreneurship to NOS and science education. The utilisation of this framework in science classes may support the development of students’ understanding of how science actually operates in society, the cross-curricular links between different subjects as well as improvement in the students’ and teachers’ interpretation of social aspects of NOS as well as enthusing students towards science classes. The SAMI cycle framework should support more authentic and engaging science classes. Within this context, the ways of enabling this conceptualisation of NOS, EOS and entrepreneurship within the SAMI cycle framework for classroom practice should also be considered. Additionally, once a topic is included in a curriculum, teachers should be able to apply it in the classroom. Therefore, improving teachers’ understanding of the topic is of importance in order to ensure that they can apply the topic in the classroom effectively. For this reason, integration into teacher education is also significant to make teachers feel knowledgeable about a topic. As previously outlines, the practical applications of social aspects of NOS, such as lesson resources and teaching materials, are understudied in the science education literature (Erduran and Mugaloglu 2013).

### 3.3.2.3. Implications of the SAMI Cycle Framework for Science Classrooms

This section presents some possible implications of the “contemporary social aspects of NOS” and the SAMI cycle framework for second and third level education. While implementing social aspects of NOS and the SAMI cycle framework into teacher education different techniques can be applied, such as argumentation, group discussion, role-play, think-pair-share, concept statement and online learning. According to Kaya et al. (2018b), a concept statement activity can be used to teach biotechnology to PSTs by integrating entrepreneurship and EOS into NOS and arguing the role of the SAMI cycle framework. A concept statement is a commonly used technique in business schools or business
departments and defined as an overview of a business plan, which is a new product or service proposal. Kaya et al. (2018b) also provided an example activity, which is presented in Figure 3-7, to apply at third-level education.

**PREPARING A CONCEPT STATEMENT:**

A concept statement is an overview of a new product or service proposal. As a team, you are expected to come up with a business idea related to science. The science topic is determined as the genetically modified organisms (GMOs). Please note that you do not have to discover something but come up with an innovative idea related to GMOs. You will develop a two-page concept statement outlining the proposal for your product or service business idea by considering the market demand for your product/service offering. Please submit your concept statement in two weeks. This document should include:

1. Scientific background (what genetically modified organism is, where and how they are used and so on.)
2. Overview of and rationale for the proposed business idea (in this part, please also discuss and clarify the role of government/state, academia, market and industry in your business idea)
3. Description of the concept (characteristics, attributes and so on.)
4. Advantages and disadvantages of the proposed idea for the society
5. Estimated budget calculation (please provide income and outcome calculation here)
6. A brief outline of the targeted buyers and their possible reaction to the offering (who will buy this and why)
7. A description of how the product or service will be sold

Figure 3-7: Concept statement activity
Source: Kaya et al. (2018b, p.18)

Argumentation can also be utilised to teach biotechnology in the context of EOS. For instance, argumentation technique was used by Erduran and Mugaloglu (2013) to highlight the economic dimensions of the genetically modified organisms (GMOs) related issues and aimed at second-level education, which includes students aged 12 - 18 approximately. This activity can also be used to implement social aspects of NOS and the SAMI cycle framework into second or third-level education, once the difficulty is adjusted according to the age. Kaya et al. (2018b) provide some other educational applications, such as arguing how science works in society in second and third-level education based on a scientist who receives an National Institutes of Health (NIH) grant.

Overall, the social aspects of NOS and the SAMI cycle framework can be applied at second and third-level education. Additionally, these topics can be divided into their elements, such as professional activities, EOS and academia-government
relationship, and each element can be applied to different topics in each weeks’ class.

3.4. CONCLUSION

Chapter Three built on Chapter Two and clarified the relevance of EOS and entrepreneurship to each other and NOS. While doing so, Chapter Three contributed to the science education literature by proposing (1) “contemporary social aspects of NOS” as an alternative way of “financial systems” and (2) the SAMI cycle framework to visualise and explain how science works in society. As the first main contribution, “contemporary social aspects of NOS” was proposed to enhance the depth and breadth of the SIS of science in NOS. Educational applications of “contemporary aspects of NOS” are also developed and implemented in PSTE, and PSTs’ perspectives are explored in the latter half of the current study. As a result of this inclusion, science teaching and learning may result in having graduates as entrepreneurial scientists who can contribute to the development and economic growth of a country (Etzkowitz 2008). From a broader perspective, EOS and entrepreneurship in NOS can aid students to engage in science classes by realising the everyday applications of science (Kaya et al. 2018b). Additionally, students can utilise EOS and entrepreneurship in NOS by providing self-employment as a career option (Achor and Wilfred-Bonse 2013) even if they do not choose science as a career option.

As the second primary contribution, the SAMI cycle framework was developed as a coherent overarching framework to conceptualise EOS, entrepreneurship and NOS and the relationship between them. This framework can support students to develop a greater understanding of cross-curricular links, which can assist them in contextualising how science works in society by demonstrating the relationship between state/government, academia, market and industry, and therefore provide a practical and visual tool for more authentic and engaging science classes (Kaya et al. 2018b). To enrich the practical applications of the SAMI cycle framework and SIS of science in science education literature, some activities have been developed, which are presented in the methodology chapter (See Section 4.4). These activities are to clarify how (a) the theoretical discussions on the integration of EOS and entrepreneurship into NOS can be pertinent, useful and practical for classroom
practice; and (b) the SAMI cycle framework can be applied in science classes. These activities are also implemented in PSTE, and PSTs’ perspectives are explored in the latter half of the current study.

Therefore, PART ONE is finalised. In PART TWO, the research questions and the paradigm and method adopted in the current study are identified as well as introducing the research design, data collection and data analysis. Moreover, the research findings relating the “contemporary social aspects of NOS” and the SAMI cycle framework are presented in PART TWO.
PART TWO:
METHODOLOGY AND FINDINGS
4 CHAPTER FOUR: METHODOLOGY

So far, the current study has investigated the relevance of EOS and entrepreneurship to NOS and how science works in society. These concepts (EOS, entrepreneurship and how science works in society) are of importance due to the contemporary accounts of science and the aim of NOS to understand how science works (See Section 1.2 for further explanation). Thus, this section explores how these concepts can be applied in PSTE. This section starts with discussing the emergence of the research questions (RQs), which helped to identify the research paradigm as the pragmatic paradigm and the method as mixed-method. Then, the research design and the data collection process are introduced, followed by data analysis. Reliability and validity of the current study and ethical considerations are argued, and the chapter is finalised with a short conclusion on how this research design helped to answer the RQs and how the approach to data analysis was appropriate to answer the RQs.

4.1. RESEARCH AIM AND QUESTIONS

This section introduces the aim of the current study and the research questions relating to this aim. The benefits of “contemporary social aspects of NOS” and the SAMI cycle framework have been discussed in the literature in Chapter Two and Three. One of the benefits is to improve PSTs’ understanding of EOS and entrepreneurship in science and their understanding of how science works in society. Thus, this exploratory study (Kothari 2004; Robson 2002) had two broad goals; (1) to explore PSTs’ understanding of the various concepts both before and after a related intervention (i.e. the contemporary social aspects of NOS and the SAMI cycle framework), and (2) to explore PSTs’ views on how these concepts apply to the science curriculum. Therefore, this exploratory study provides an evidence of the usefulness of the SAMI framework and Contemporary Social aspects of NOS by presenting an increase in PSTs’ understanding of the concepts.
These concepts are new to science education in Ireland so it is expected that preconceptions may be limited.

The current study also aims to explore, design, develop, adapt, apply and evaluate new educational activities to facilitate this integration since EOS and entrepreneurship in NOS and how science works in society are new contexts in science education in Ireland. According to the research aim and objectives, research questions (RQs) were developed as illustrated in Figure 4-1.

Figure 4-1: Research questions and how literature informs the research questions

Figure 4-1 demonstrates the two RQs and their two sub-questions and the literature that informs them. In this sense, theoretical discussions have been conducted on the relevance of EOS and entrepreneurship to each other and NOS and science education. Based on this relevance, “financial system” was reconceptualised as “contemporary social aspects of NOS” and this brought up RQ-1. Then, the SAMI cycle framework was proposed based on the conceptualisation of NOS, EOS and entrepreneurship. This framework elucidates the relationship between the state/government, academia, market and industry and visualises how science works...
in society. Thereby, RQ-2 emerged. The role of NOS, EOS and entrepreneurship in the JCSS has also been presented in all previous chapters. Therefore, RQ-1.1 and RQ-2.1 were engendered. The paradigm of the current study is discussed in the following section.

4.2. RESEARCH PARADIGM: PRAGMATIC PARADIGM

This section defines what a paradigm is, and introduces the pragmatic paradigm as the paradigm of the current study. Guba and Lincoln (1994, p.35) defined a paradigm as a “basic set of basic beliefs that guide action”. A paradigm refers to a worldview that determines the nature of the world and the individual’s place and the range of possible relationships within it. Likewise, Cohen et al. (2011) defined a paradigm as:

- a way of looking at or researching phenomena, a worldview, a view of what counts as accepted or correct scientific knowledge, … a way of pursuing knowledge, consensus on what problems are to be investigated and how to investigate them, typical solutions to problems, and an understating that is more acceptable than its rivals.

(Cohen et al. 2011, p.5)

There are different paradigms, such as positivist, post-positivist, interpretivist, constructivist, critical theory, feminist theory and pragmatic paradigms (Creswell 2003; Mertens 2005). Additionally, there is a distinction between the qualitative and quantitative method regarding the nature of knowledge, such as understanding of the world and the purpose of research (Mackenzie and Knipe 2006). In this case, the terms (the qualitative and quantitative method) are used as a paradigm (Johnson and Onwuegбuzie 2004). However, these terms can also be used as research methods as done in the current study (Mackenzie and Knipe 2006). Within this context, different paradigms align with different methods. Predominantly, the positivist paradigm aligns with the quantitative research (Mertens 2005), the interpretivist paradigm aligns with the qualitative research (Cohen et al. 2011), the pragmatist paradigm aligns with the mixed-methods research (Creswell 2003).

The current study adopts a pragmatic paradigm. A pragmatic paradigm is concerned with the results of actions and the ascriptions of meanings to phenomena
The primary features and assumptions of the pragmatic paradigm and how the current study fulfils these features and assumptions are presented in Table 4.1.

Table 4.1: Main features and assumptions of pragmatic paradigm and how the current study fulfils these features and assumptions

<table>
<thead>
<tr>
<th>Paradigm</th>
<th>Features and Assumptions</th>
<th>How The current study Fulfils the Paradigm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pragmatic</td>
<td>• This paradigm is not committed to any one reality (Creswell 2003)</td>
<td>• The current study does not commit to any one reality since there is a focus on each participant’s own reality in the qualitative data</td>
</tr>
<tr>
<td></td>
<td>• This paradigm is problem centred (Creswell 2003)</td>
<td>• The current study embraces different techniques to define what works to answer the research problem</td>
</tr>
<tr>
<td></td>
<td>• Usually mixed-methods is used (Feilzer 2009)</td>
<td>• The current study supports that participants knowledge can be investigated deeply by using mixed methods, and applies mixed-methods</td>
</tr>
</tbody>
</table>

Pragmatic paradigm refers to a set of assumptions about the nature of reality, but it does not deal with what reality is. Instead, pragmatist researchers focus on the “what” and “how” of the research problem (Creswell 2003; Mackenzie and Knipe 2006). Pragmatists rejected “the scientific notion that social inquiry was able to access the ‘truth’ about the real world solely by virtue of a single scientific method” (Mertens, 2005, p.26). Rather than adopting a single scientific approach, pragmatists adopted a problem-centred approach which approaches to the research problem with the “what works” perspective. In this sense, pragmatist researchers centralise and focus on the research problem and apply different approaches to understand the problem (Creswell 2003).

According to Tashakkori and Teddlie (2003):

> the essential idea of pragmatism is to reject the either-or choices and the metaphysical concepts associated with the paradigm wars and to focus instead on ‘what works’ in getting research questions answered.

(Tashakkori and Teddlie 2003, pp.20-21)

That is, different methods, techniques and procedures are applied to solve the research problem (Mackenzie and Knipe 2006; Punch 2009; Tashakkori and
The practicality of solving the research problem in a practical world is the focus of pragmatist researchers (Cohen et al. 2011; Creswell 2003; Mackenzie and Knipe 2006) whether research permits the researcher to learn what s/he wanted to find out regardless of the data type (Feilzer 2009). Relating the method adopted in the pragmatic paradigm, pragmatist research is often associated with the mixed-methods approach (Mackenzie and Knipe 2006; Punch 2009; Tashakkori and Teddlie 2003). Therefore, the research method of the current study is determined as mixed-methods and how the current study adopts mixed-methods is discussed in the next section. Since mixed-methods combines the qualitative and quantitative method, how the current study fulfils the features of these research methods are also discussed.

4.3. RESEARCH METHOD

There are three types of research methods exist, namely qualitative, quantitative and mixed-methods. The research method of the current study is determined as mixed-methods. Since mixed-methods combines the qualitative and quantitative method, how the current study fulfils and adopts the features of these research methods is discussed in this section. Furthermore, the pros and cons of each method have been examined and explored, and the reason for choosing the methods have been justified.

4.3.1. Qualitative Research Method

This section explains the features, advantages and disadvantages of using the qualitative research method and explores how this method is applied in the current study. Qualitative researchers are interested in people’s perception of the world (Bryman 2012) and aim to get a complete detailed understanding of the perceived world. That is, this approach deals with uncovering knowledge about people’s feelings, behaviours, and thoughts (Thorne 2000). Features of qualitative research and how the current study fulfils these features are explained in Table 4.2.
Table 4.2: Features of qualitative method and how the current study fulfils these features

<table>
<thead>
<tr>
<th>Features of Qualitative Method</th>
<th>How The current study Fulfils These Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Making sense of the data from the participants’ view of the situation (Cohen et al. 2011)</td>
<td>• By making sense of the data from the participants’ perceptions and understandings of social aspects of NOS and the SAMI cycle framework relationship</td>
</tr>
<tr>
<td>• Focusing on discovering a theory rather than testing one (Bryman 2012; Creswell 2003)</td>
<td>• By focusing on developing a framework to explain how science works in society, and exploring new elements of social aspects of NOS</td>
</tr>
<tr>
<td>• Using different techniques, such as interview, observation and role-playing</td>
<td>• By collecting data through the interview, group discussion, project development (concept statement and crisis management activities) and role-play activity (including diagram construction, group discussion and individual open-ended questions)</td>
</tr>
<tr>
<td>• Analysing the data by such methods as thematic analysis (O’Leary 2004)</td>
<td>• By analysing the majority of data with thematic analysis</td>
</tr>
</tbody>
</table>

There are also some criticisms of the qualitative approach. For example, according to Bryman (2012, p.383), “the connection between theory and research is somewhat more ambiguous than in quantitative research”. Likewise, qualitative research results might be unique to the group that participated in the research (Johnson and Onwuegbuzie 2004). Based on all these, Table 4.3 was developed to summarise the advantages and limitations of the qualitative method. Moreover, the qualitative methods contribute to determining the causes of a phenomenon and provides alternative perspectives of the topic investigated (Dixon-Woods and Fitzpatrick 2001) and more in-depth information about the research context by gaining more insight into where participants' attitudes and opinions come from (Osborne and Hennessy 2003).
As seen in Table 4.3, there are limitations of qualitative research as well as advantages. How these limitations were decreased in the current study is discussed at the end of Section 4.3.3. There are different qualitative research instruments. The ones that have been used in the current study are introduced in the following subsection.

4.3.1.1. Qualitative research instruments used in the current study

There are different qualitative data collection instruments. The interview, story-based group discussion, concept statement, focus group discussion, crisis management and role-play are introduced in the following paragraphs as they were used in the current study. These qualitative data collection instruments except the interview and focus group discussion are also the activities which were used during the interventions in the current study.
An interview is “a two-person conversation initiated by the interviewer for a specific purpose of obtaining research relevant information” (Cannell and Kahn 1968 cited in Cohen et al. 2011, p.271). Interviews allow the interviewee to express themselves by explaining situations from their own view (Cohen et al. 2011). Therefore, interviews were applied in the current study due to conducting research aiming to determine participants’ understandings of a particular topic. The construction of the interview includes a variety of decisions, such as the structure of the interview, the type of questions and the range of topics. Concerning the structure of the interview, there are a variety of interview formats starting from unstructured conversations to highly structured interviews (Kvale 1996). Some researchers prefer a carefully planned set of questions (highly structured interview).

Nevertheless, highly structured interviews do not allow the researcher “to follow up on unexpected topics or individual differences that emerge during the interview” (Brenner 2006, p.362). Some other researchers prefer the semi-structured interview. In the semi-structured interview, there are some core questions to be posed, and follow-up questions can be asked during the interview to build on the responses received. Therefore, the semi-structured interview has the flexibility of following up on unexpected topics or individual differences emerging during the interview. The current study employed the semi-structured one-to-one interviews to provide more in-depth information about the reasons behind the changes in participants’ understandings and their experiences of the activities. The rationale for this choice is that:

1. Semi-structured interviews have fewer restrictions for probing unexpected situations (Brenner 2006). For example, when there is a case which might be important for the research conducted, the researcher has the opportunity to probe it.
2. Semi-structured interviews allow researchers to modify and adjust the interview questions to explore a deeper understanding of participants’ views (Silverman 2013).
3. Semi-structured interviews provide an opportunity for all participants to add new aspects and angles to the topic investigated (Kvale 1996).
A group discussion in teaching aims to bring a group of students together to argue on a given topic to come up with ideas, solve problems or make comments. The reason for selecting a group discussion is due to it being an effective teaching method in science education (Alexopoulou and Driver 1996). The reason for developing an activity based on a real science story is that the historical science stories are important in NOS teaching (Allchin 2011; Allchin et al. 2014). In the development process of this activity, its aim was determined at the beginning so as to improve PSTs’ understandings of social aspects of NOS, in particular, EOS and entrepreneurship as its contemporary aspects, and of how science works in society including the relationship between the state/government, academia, market and industry. The primary focus of the activity was the contemporary social aspects of NOS, and the relationship between academia, market and industry.

A concept statement is an overview of a business plan. According to Etzkowitz (2008), a business plan is an extremely effective way to improve someone’s understanding of entrepreneurship. Also, a concept statement is often used in entrepreneurship education before developing a detailed business plan (ibid). One of the main aims of the current study is to improve participants’ understanding of entrepreneurship and EOS in NOS. Therefore, a concept statement activity was chosen as one of the teaching methods to test this. The concept statement activity can play a role as a project assignment for different science subjects either as a group or as an individual project assignment (Kaya et al. 2018b). Furthermore, a concept statement activity can be conducted with or without utilising a specific topic. In this study, written qualitative data was collected through concept statement activity, and therefore it was used as a research method.

A focus group is a form of a group interview that utilises the communication between research participants to generate data (Kitzinger 1995). In this technique, participants are encouraged to talk to each other rather than the researcher posing the questions to each participant.

the idea behind the focus group is that group processes can help people to explore and clarify their views in ways that would be less easily accessible in a one to one interview

(Kitzinger 1995, p.299)
In a focus group, the researcher provides a series of questions and participants discuss these questions. This qualitative data collection instrument aims to collect information about the process that participants go through to develop their concept statement and to decide whether each student played an equal role in this process. Within this aim, if participants were interviewed individually, there was a possibility of conflict between the participants’ answers, and this can be difficult to solve. However, when conducting a focus group discussion, if there is conflict, it can be clarified at that moment in time. Therefore, a focus group was chosen as one of the data collection instruments.

The crisis management is a commonly used phrase in business (e.g. Pearson and Claire 1998; Ritchie 2004). Many other disciplines also use crisis management strategies, such as political sciences, environmental management, geography/natural hazards management and technology (ibid). These disciplines are relevant to different sciences, such as environmental sciences. Furthermore, there are a variety of crisis types that can impact organisations, such as information sabotage, product tampering, copyright infringement, plant explosion, environmental spill and natural disaster (Pearson and Claire 1998). In this sense, crisis management may be relevant and beneficial in science as an intuitional system and scientific organisations, such as NASA. Therefore, an activity was developed relating the crisis management. In this activity, a crisis was created, and this crisis included risk-taking and problem-solving ability. The main idea behind this activity was to increase participants’ prediction of potential risks and support them to find possible solutions for these risks before they turn into a crisis. This activity could be relevant to science by increasing decision-making, problem-solving and critical thinking skills as well as being relevant to entrepreneurship by increasing the same skills in the addition of risk-taking skills. Thus, this activity aimed to improve participants’ risk-taking and problem-solving skills, which are common NOS and entrepreneurship skills. Additionally, it also aimed to increase participants’ awareness of possible negativities included in entrepreneurial science. In this study, written qualitative data was collected through crisis management activity, and therefore it was used as a research method.

Role-play is an educational teaching strategy which can be used with large or small groups (Cohen et al. 2011). Therefore, a role-play activity was developed in the
current study. This activity aims to improve participants’ understanding of (1) the role of the SAMI cycle framework concepts (EOS, entrepreneurship and NOS) in explaining how science works in society, (2) elements of SIS of science, and (3) the relationship between the SAMI cycle framework themes which are the state, academia, market and industry. The main goals of the activity were to improve participants’ understanding of the elements of the SAMI cycle framework and their relationship. In this study, written qualitative data was collected through role-play activity, and therefore it was used as a research method. Further information about how these research instruments have been developed and used are presented in Section 4.4, and their validity and reliability are discussed in Section 4.6.

4.3.2. Quantitative Research Method

This section explains the features, advantages and disadvantages of using quantitative research methods and explores how this method is applied in the current study. Quantitative researchers are interested in facts (Bell 2010) and aim to identify the truth by scientific method (Thorne 2000). Quantitative researchers are concerned with quantifiable data collection and analysis by measuring, generalising and replicating the data (O’Leary 2004), and they focus on testing a theory rather than discovering one (Bryman 2012; Creswell 2003). Features of quantitative research and how this study fulfils these features are explained in Table 4.4.

As mentioned in Table 4.4, the quantitative data were collected by questionnaires in once-off PSTE. Oppenheim (1996) defines a questionnaire as not only a question list or a form to be filled out but also a scientific instrument to collect and measure some specific data. Given the limited time and the sample size, the changes in participants’ understandings could only be assembled by applying a questionnaire in this study. Quantitative data has been collected in this study to answer RQ-1 and RQ-2.
Table 4.4: Features of quantitative method and how this study fulfils these features

<table>
<thead>
<tr>
<th>Features of Quantitative Method</th>
<th>How This Study Fulfils These Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Involving larger sample sizes than qualitative approaches in order to increase generalizability of data (Cohen et al. 2011)</td>
<td>• By involving 50 participants</td>
</tr>
<tr>
<td>• Using different techniques, such as questionnaires and tests</td>
<td>• By collecting data through questionnaires</td>
</tr>
<tr>
<td>• Analysing the data by statistical analysis (O’Leary 2004)</td>
<td>• By analysing data with Statistical Package for the Social Sciences (SPSS)</td>
</tr>
</tbody>
</table>

There are some criticisms of the quantitative approach. For example, the statistical measurement of some aspects of the world is not possible (Dubos cited in Peshkin 1993, p.23). Over-relying on measurements hinders the connection between research and real-life (Bryman 2012). Missing this connection may result in inaccurate theories. Thus, this method cannot probe the causes of the problems and provides superficial information about the research phenomena. Based on all these, Table 4.5 is developed to summarise the advantages and disadvantages of using the quantitative research method.

Table 4.5: Advantages and disadvantages of the quantitative research

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>• It is generalizable due to the larger sample size (O’Leary 2004)</td>
<td>• It is limited in terms of understanding the phenomena due to not being open to last minute changes.</td>
</tr>
<tr>
<td>• It has a less possibility of researcher bias due to being detached from the research subject (Cohen et al. 2011)</td>
<td>• It provides superficial information about the research since it is difficult to probe the information</td>
</tr>
<tr>
<td>• It is reliable due to its objectivity (Bryman 2012)</td>
<td>• It treats a human being like an object (Bryman 2012)</td>
</tr>
<tr>
<td>Quantitative Research Method</td>
<td>• The researcher might miss out on phenomena occurring due to focusing on theory or hypothesis testing</td>
</tr>
<tr>
<td></td>
<td>• Produced knowledge might be too abstract to directly apply to situations (Bryman 2012; Cohen et al. 2011)</td>
</tr>
</tbody>
</table>
As seen in Table 4.5, there are limitations of the quantitative research as well as its advantages. How these limitations were decreased in this study is discussed at the end of Section 4.3.3. There are different quantitative research instruments. The ones that have been used in the study are introduced in the following sub-section.

4.3.2.1. Quantitative research instruments used in the study

There are different quantitative research instruments. The questionnaire is introduced here since it was used in this study. A questionnaire is a widely used instrument for collecting survey information, which usually provides numerical data and can be administered without the presence of the researcher (Birdthistle 2004). The aim of the questionnaire in this study was to define participants’ understandings both pre and post the once-off intervention in relation to (1) the contemporary social aspects of NOS, which are EOS and entrepreneurship, and (2) the inclusion of the contemporary social aspects of NOS and the relationship between state/government, academia, market and industry (the SAMI cycle framework) in the JCSS.

There are a variety of questionnaires; however, for all types of questionnaires, the rule is that the bigger sample size requires the more structured, close and numerical questionnaire (Cohen et al. 2011). Whilst an unstructured questionnaire is preferred for a small sample, a structured questionnaire is favoured for the large sample since it could be difficult to analyse all of the open data in a limited time. This study employed a semi-structured questionnaire, which contains open-ended questions as well as structured questions (Adejimi et al. 2010; Cassell and Symon 2004; Cohen et al. 2011). The reason for employing a semi-structured questionnaire in this study is that (1) the sample size is suitable for semi-structured questionnaires, (2) semi-structured questionnaires give participants the freedom to a certain extent to express themselves, and (3) it is suitable for the aim of the study. Moreover, a five-point Likert scale was used in this semi-structured questionnaire. Likert scales were chosen over other scales because Likert scales are more valid than other scales (Ray 1990). There are many reasons for preferring a five-point Likert scale over the other scales. These reasons are outlined below:
1. It has a neutral point (Guy and Norvell 1977; O’Muircheartaigh and Helic 2000) which provides respondents with a middle range alternative with no expression of agreement/disagreement.
2. It does not force participants to choose a side (O’Muircheartaigh and Helic 2000). That is, participants can remain neutral by ticking the box “neither agree nor disagree”.
3. When a neutral point is neglected there is a high tendency to get no response (Guy and Norvell 1977).
4. It is more reliable than a scale with fewer points (Munshi 2014).
5. It is more time effective than a six or seven-point scale (Ray 1990).

Further information about how the research questionnaire has been developed and used are presented in Section 4.4, and its validity and reliability are discussed in Section 4.6.

4.3.3. Mixed-Methods

This section explains the features, advantages and disadvantages of using the mixed-methods research and explores how this method is applied in this study. Furthermore, how the limitations of the qualitative and quantitative research were decreased is discussed at the end of the section. As mentioned previously, the study employs a mixed-methods approach. The mixed-methods approach aims to combine the strengths of qualitative and quantitative methods (Cohen et al. 2011; Tashakkori and Teddlie 2003). The mixed-methods provide a complete understanding of the social world and research phenomena studied through using different perspectives to understand a variety of values, stances and positions (Johnson and Onwuegbuzie 2004) since each method can fill the gap left by the other.

The mixed-methods approach includes all the advantages of qualitative and quantitative data. For example, the mixed-methods allows pursuing unexpected results (Bryman 2012) and provides rich data in different forms. (Osborne and Hennessy 2003; Sosulski and Lawrence 2008). This can prevent losing potentially useful data (Gorard and Taylor 2004). Researchers using mixed-methods can both generate and test a theory, answer a more complete range of RQs, and provide a
more evidence-based conclusion through convergence and collaboration of findings (Johnson and Onwuegbuzie 2004). However, there are also limitations of the mixed-methods research. For example, conducting mixed-methods research requires higher-level skills since both the qualitative and quantitative research requires specialised expertise. It can also be more expensive and time-consuming (Johnson and Onwuegbuzie 2004).

There are different ways of combining qualitative and quantitative research. For example, according to Bryman (2012), some of them are triangulation, offset, completeness, different RQs, explanation, instrument development, illustration, confirm and discover, diversity of views, and enhancement. According to Rossman and Wilson (1994), there are four different ways of employing mixed-methods:

1. The method perspective: the research procedure involves a quantitative method and a qualitative method
2. The methodological perspective: moves beyond a mixing of methods and looks at a mixed approach in all aspects of the research process, e.g. aims and RQs, data collection and analysis
3. The paradigm perspective: relates to the philosophical perspectives that the researcher brings to their research
4. The practice perspective: a mixed methods approach emerges as the research is being conducted.

This study adopts the first way of employing mixed-methods - the method perspective - as it involves at least one quantitative method and one qualitative method (Greene et al. 1989; McCormack 2010). Furthermore, Robson (2002) presents the main reason for choosing a mixed-methods as in this study is through triangulation. Triangulation is defined as the use of more than one methods of data collection. A mixed-methods approach is commonly preferred for educational research due to its positive effect on triangulation (Cohen et al. 2011; Johnson and Onwuegbuzie 2004). Triangulation in social sciences attempts to:

map out, or explain more fully, the richness and complexity of human behaviour by studying it from more than one standpoint and, in so doing, by making use of both quantitative and qualitative data.

(Cohen et al. 2011, p.195)
Moreover, using mixed-methods also saves time. For example, in this study, collecting qualitative data from 50 participants, transcribing data and conducting data analysis could take a long time. However, collecting the quantitative data, in the form of questionnaires, from all participants and supporting this data with the qualitative data collected by interviewing some participants saved time. Furthermore, supporting the quantitative data with the qualitative data facilitated the interpretation of the data by developing explanations of the reasons for the relationships between variables. Triangulation also adds breadth and depth to the research analysis and emerging data (Fielding and Fielding 1986). There were two main interventions in this study; (1) the research topic was taught more than once (continuous) to three PSTs (n = 3) in the first intervention with the aim of collecting in-depth information on the participants’ understandings, and (2) the research topic was taught once to 50 PSTs (n = 50) in the second intervention having the same aim. Therefore, while the qualitative method was applied in the first intervention, the mixed-methods was applied in the second intervention, in which the quantitative data was collected to understand participants’ understandings, and the qualitative data was collected to probe further information about their perspectives.

As mentioned in section 4.3.1 and 4.3.2, there are limitations of adopting only qualitative or quantitative research, such as objectivity, generalisability, replicability, validity and flexibility (being open to last minute changes). Yet, conducting mixed-methods research decreases these limitations, increases the validity and reliability of the research due to triangulation (Greene et al. 1989). For example, in order to overcome the issues of objectivity, validity and reliability, a triangulated approach was adopted by collecting quantitative and qualitative data to support each other. Adopting a triangulated approach increased the flexibility of the study to last minute changes, the richness of the data by probing the information and validity and reliability of this study. Furthermore, using a mixed-methods approach strengthened this study by preventing to overlook the phenomena and providing further data. Triangulation is further discussed in Section 4.6.

To overcome the issues of replicability, “thick description” was used. The thick description provides details, conceptual structures and meanings in the study (Ponterotto 2006). Concerning generalisability of the study, even though the research data is statistically not representative due to its small sample size, it can
be an effective way to investigate and explore unknown aspects and key factors of the study. Therefore, the limitations of qualitative and quantitative research were decreased as far as possible by using a mixed-methods approach. After defining the study as a mixed-methods study, the research design process was started. In the next section, research design is introduced and elucidated.

4.4. RESEARCH DESIGN

This section introduces the research design, including the research samples, the development of the research instruments, the pilot studies and the data collection process. This study primarily included one research intervention, in which the research topic has been taught over a number of different sessions and approaches to three PSTs (n = 3) over a period of six weeks. The first intervention aimed to collect in-depth information on the participants’ understandings. Thus, this study initially aimed to answer RQ-1, RQ-2 and their sub-questions. However, it was aimed to extend the study beyond a small group and provide an opportunity for other students to explore the topic. When an opportunity emerged to engage with a larger group during a two-hour teaching period, another intervention was designed. In the second research intervention, the research topic was taught once with 50 PSTs (n = 50), with the same aim as the first intervention. Therefore, the current study was designed in two parts; (1) in the first intervention, PSTs were exposed to the research topic four times, which was referred to the continuous PSTE, and (2) in the second intervention, PSTs were exposed to the research topic once, which was referred to the once-off PSTE in this study.

Based on the studies discussed in Section 1.2.5.1, the continuous PSTE was defined as the involvement of learners in an ongoing teaching process of applying different activities to develop an understanding of the given topic. The once-off PSTE was determined as the involvement of learners in a teaching process once by applying one or more activities providing a snapshot of a given area to develop an understanding of the given topic. The involvement of once-off PSTE in this study is important since the continuous teaching of a subject topic might be problematic.

11 RQ-1: How is PSTs’ understanding of contemporary social aspects of NOS influenced by the research intervention?
12 RQ-2: How is PSTs’ understanding of the relationship between state/government, academia, market and industry influenced by the research intervention?
due to the packed schedule of PSTE programmes (Broggy et al. 2015). Therefore, while continuous exposure to a topic would be best in terms of understanding, this may not always be feasible within a busy undergraduate programme. These two research designs including their sample sizes, duration, research instruments and data analysis methods are summarised in Figure 4-2.

Figure 4-2: Research methodology design

Figure 4-2 is detailed in the following sections. After introducing the research methodology design, to comprehend the organisation of the current study and research instruments, the RQs and their targeting activities are introduced in Figure 4-3.

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13 “n” stands for the number of participants in Figure 4-2.
To comprehend the research process better, in the following sections, the research context and the research sample are introduced. Then, the continuous PSTE is presented including the development of the research instruments, the pilot of the study and the data collection process. Finally, the once-off PSTE is presented including the development of the research instruments, the pilot of the study and the data collection process.

### 4.4.1. Research Context and the Research Sample

This section explains the research context and the research sample selection process and provides the demographic background of the research participants. The study took place in a university in the mid-west of Ireland. As mentioned in Section 1.2.5, the focus of the current research study is the concurrent teacher education
programme. The concurrent programme allows pre-service teachers to study education-specific components and school placement while studying their chosen academic discipline. As the study focuses on pre-service science teachers (PSTs), the second and third-year PSTs were invited to participate in the study. This is because the first-year PSTs are adapting to a new environment and not be sufficiently established within the university. The fourth-year PSTs have a significant school placement and tend to be busy completing their Final Year Project (FYP). As a result, it can be difficult to reach them. Therefore, an email was sent to the second and third-year PSTs regarding participating in the continuous PSTE part of the study. Three third-year students applied to participate in the study. While waiting for some other PSTs to apply to be involved in the study, the pilot study was conducted with four participants to see whether enough data could be collected with this sample size. As a result of the pilot study, adequate data were collected to analyse. Due to being able to collect enough data with a similar sample size, the continuous PSTE was conducted with three third-year PSTs. After gathering enough data to answer RQs at the end of the main research of the continuous PSTE, further data was not collected.

Concerning the once-off PSTE, the researcher was offered a two-hour teaching slot in a third-year module “SE4006: Science Teaching”. This module was relevant to the study due to aiming to incorporate new developments into the JCSS as well as having a focus on cross-curricular links. Permission was granted from the module leader to conduct the current study as part of the timetabled modules’ class. An email was sent to students who were taking this module to let them know that this research would be conducted in this module, attendance was voluntary, and it will not affect their grades. Therefore, the once-off PSTE was conducted with 50 PSTs. After selecting the sample for the once-off PSTE, a sample for conducting the interviews was required. Within this purpose, a tick box was included at the end of post-questionnaire to ask for volunteers for an interview. Three PSTs volunteered to participate in the interviews. Therefore, the sample selection was completed.

4.4.1.1. Profile of participants

Concerning the participants’ demographics, both the continuous and once-off PSTE participants were “LM092: Bachelor of Science (Education) in Biology and
Chemistry or Physics or Agricultural Science” students. Three continuous PSTE participants were named Anne, Mary and Lisa to protect the anonymity of the participants. This group was comprised of all female PSTs who were 21 years old. While only Mary has completed a module(s) on entrepreneurship and/or economics at post-primary level and/or university, none of them had an entrepreneurial background, and all of them (n = 3) had someone in their family who has been involved in entrepreneurial activities and/or comes from an economics background. Anne, Mary and Lisa were also involved in the once-off PSTE. However, they worked in a group together to decrease their impact on the results of the other participants. Furthermore, Anne and Mary took part in the interviews that were conducted at the end of the once-off PSTE.

In the once-off PSTE, 41 out of 50 PSTs (including Anne, Mary and Lisa) were female with the average age of 21. There was only one participant who was 42 years old. 15 out of 50 PSTs have completed a module(s) on entrepreneurship and/or economics at post-primary level and/or university, one PST had an entrepreneurial background, and 25 out of 50 PSTs had someone in their family who has been involved in entrepreneurial activities and/or comes from an economics background. Participants’ demographic information is presented in Table 4.6 through the continuous and once-off PSTE.
Table 4.6: Demographic information demonstrated with percentages in the continuous and once-off PSTE

<table>
<thead>
<tr>
<th>Demographic information</th>
<th>Options</th>
<th>Continuous PSTE</th>
<th>Once-off PSTE including Anne, Mary and Lisa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Female</td>
<td>100%</td>
<td>82%</td>
</tr>
<tr>
<td></td>
<td>Male</td>
<td>0%</td>
<td>18%</td>
</tr>
<tr>
<td>Average Age</td>
<td></td>
<td>21</td>
<td>21</td>
</tr>
<tr>
<td>Module completion on entrepreneurship and/or economics at post-primary level and/or university</td>
<td>Yes</td>
<td>33%</td>
<td>30%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>67%</td>
<td>70%</td>
</tr>
<tr>
<td>Entrepreneurial background</td>
<td>Yes</td>
<td>0%</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>100%</td>
<td>98%</td>
</tr>
<tr>
<td>Having a family member who has been involved in entrepreneurial activities and/or comes from an economics background</td>
<td>Yes</td>
<td>100%</td>
<td>50%</td>
</tr>
<tr>
<td></td>
<td>No</td>
<td>0%</td>
<td>50%</td>
</tr>
</tbody>
</table>

At the end of once-off PSTE, three out of these 50 PSTs were interviewed; Anne and Mary, and another PST involved in the once-off PSTE only, who is named Mark to protect his anonymity. Mark is a 42-year-old male, who has neither completed a module on entrepreneurship and/or economics nor an entrepreneurial background. He also does not have any family member who has been involved in entrepreneurial activities. The continuous PSTE is introduced in the next section.

4.4.2. Design of the First Intervention and the Data Collection: The Continuous PSTE

This section introduces the continuous PSTE including the development of the research instruments, the pilot of the study and the data collection process. The continuous PSTE was defined as the involvement of learners in an ongoing process of applying different activities to develop the understanding of the given topic. During the continuous PSTE, different activities relating to the research topic were performed with three PSTs (n = 3) for six weeks. This aspect of the study aimed to
answer RQ-1\textsuperscript{14} and RQ-2 All of the research instruments in the continuous PSTE are qualitative instruments, as described above. In total, six different data collection instruments were developed for the continuous PSTE. These research instruments were introduced in Section 4.3.1.1, and their development process is explained in the next section.

4.4.2.1. Developing Instruments of the Continuous PSTE

In this section, the six data collection instruments for the continuous PSTE are introduced. In the current study, while interviews and the focus group discussion served as the data collection instruments, story-based group discussion, concept statement and crisis management activities are used as both activities in the first intervention and as sources of data.

4.4.2.1.1. Pre-interview

The pre-interview aimed to examine participants’ existing understanding of social aspects of NOS, in particular, EOS and entrepreneurship, and how science works in society including the relationship between the state/government, academia, market and industry. Using Kvale (1996) as a guide to questions, the interview questions were written under five themes, namely SIS of science in NOS, the SAMI cycle framework, EOS, entrepreneurship and educational applications. There were two SIS of science-related questions to let participants familiarise themselves with the concepts. Two questions were targeting the SAMI cycle framework, including a diagram construction question, to determine the changes in participants’ understanding of how science works in society. Following this, four EOS questions and then four entrepreneurship questions were posed. This interview was concluded by asking three educational application questions regarding the use of EOS and entrepreneurship in science education. Therefore, there were 15 core questions gathered under five themes in this semi-structured interview (See Appendix 4), designed to answer RQ-1 and RQ-2, including their sub-questions (See Figure 4-3).

\textsuperscript{14} RQ-1: How is PSTs’ understanding of contemporary social aspects of NOS influenced by the research intervention?
4.4.2.1.2. Story-based Group Discussion

This activity (See Appendix 5) aimed to improve participants’ understanding of social aspects of NOS and the relationship between academia, market and industry (the SAMI cycle framework) with the primary focus of EOS and SIS of science definition. To design this activity, an activity developed by Erduran and Mugaloglu (2013) was utilised (See Appendix 6). Erduran and Mugaloglu’s (2013) activity provides a short scenario about OncoMouse\(^\text{15}\), two claims about its patenting and some evidence statements to be used by participants to support their ideas and/or refute other debaters’ ideas.

Story-based group discussion was designed for third-level students (university and college students). In this activity, a story about the discovery of graphene was provided. This story was chosen due to including the parts related to EOS, entrepreneurship and some elements of the SAMI cycle framework, such as academia, industry, and market. Additionally, the feedback provided in the pilot research influenced this choice. Next, the social-institutional system was defined according to Erduran and Dagher (2014a, 2014b) to facilitate participants’ understanding. Based on this definition, two claims were written to discuss whether science is a social-institutional system. Then, to defend their claims, participants were asked to select their own evidence statements in the story rather than being provided with them. Finally, instructions including the steps to follow during the discussion were provided to guide participants in conducting a group discussion.

The steps were determined based on IDEAS Project conducted by Osborne et al. (2004b), and the research conducted on the use and quality of argumentation in science education (Erduran et al. 2004; Osborne et al. 2004a). At the end of story-based group discussion, participants were questioned about the elements of the SAMI cycle framework. The reason for that is to explore the changes in their understanding of the SAMI cycle framework after this activity. Therefore, this activity was designed to answer only RQ-1 and RQ-2 (See Figure 4-3).

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\(^{15}\) OncoMouse is a mouse that became susceptible to cancer by genetic modification.
This activity (See Appendix 7) targeted the contemporary social aspects of NOS and the SAMI cycle framework; however, the primary focus was the role of entrepreneurship in science. To design the concept statement for this study, the researcher attended a class where a business lecturer uses concept statements in her teaching. Based on all this guidance and relevant literature review, a concept statement was adapted to suit science education by intertwining a scientific and business context. To adapt it to science education, a template about preparing a concept statement was prepared, the language was simplified to make this activity relevant and suitable for undergraduate students, and some elements were rewritten to provide relevance to science education. For example, instead of only asking for a business idea, participants were asked to come up with a business idea related to science; or instead of only asking the rationale for the proposed business idea, participants were asked to write the rationale behind the business idea by providing scientific knowledge behind it. Finally, some background knowledge and relevant terminology were provided to facilitate participants' understandings since it is presumed that they do not have high-level knowledge of entrepreneurship. Participants were asked to develop a two-page concept statement in two weeks which is the time given at the business school. Therefore, this activity provided data towards answering RQ-1 and RQ-2 (See Figure 4-3).

To follow up with the concept statement activity, a focus group discussion was conducted. Focus group discussion (See Appendix 8) aims to identify how participants developed their concept statement, and therefore collect further data related to the concept statement activity. The literature was reviewed to develop the main theme of questions in relation to the aims of the activity, and six main questions were developed. Next, based on six main questions, 12 example questions were developed to shape and facilitate the flow of the participants’ discussion within the context of the concept statement. In Table 4.7, the six main questions are presented in the left column, and the 12 example questions are presented in the right column.

Table 4.7: Main questions and their example questions in the context of concept statement
These 12 questions were provided to participants to facilitate the focus group discussion. The steps for conducting a discussion was also presented to the participants. These steps were similar to the story-based group discussion and also determined based on IDEAS Project (Osborne et al. 2004b), and the research conducted on the use and quality of argumentation in science education (Erduran et al. 2004; Osborne et al. 2004a). This activity was also targeting only RQ-1 and RQ-2 (See Figure 4-3).

4.4.2.1.4. Crisis Management

This activity (See Appendix 9) was also related to the concept statement activity and aimed to improve participants’ risk-taking and problem-solving skills, which are common NOS and entrepreneurship skills.

The researcher attended a class where a lecturer uses crisis management in her teaching. Based on all this guidance and relevant literature review, a crisis
management activity was adapted to suit science education by intertwining a scientific and business context. To conduct this activity, participants’ concept statements were read, and a possible crisis was created from their responses, for example, a copyright issue came up in the participants’ concept statement. Based on this, an introduction was provided about what the issue was and what was missing in the concept statement. Next, some guidance in solving the issue were provided. Having given the example of a crisis situation, participants were asked to come up with a solution in one week to overcome the crisis created. This activity was designed to facilitate answering the same RQs with the concept statement activity, which are RQ-1 and RQ-2 (See Figure 4-3).

4.4.2.1.5. Post-interview

The post-interview (See Appendix 10) aimed to explore students’ understanding of social aspects of NOS, in particular, EOS and entrepreneurship and how science works in society after participating in the study. This was a semi-structured one-to-one interview including the same 15 questions that were asked in the pre-interview with the addition of seven questions. Some of these additional questions were added to the interview to explore participants’ personal and learning experiences during the intervention. Personal experiences include their feelings toward the activities, such as their likes and dislikes. Learning experiences include the most and least beneficial parts of the activities, and what they have learned from each activity. At the beginning of the interview, participants were asked again to construct a diagram illustrating how science works in society by using the words provided. This diagram construction question was utilised to determine the changes in participants’ understanding of how science works in society. This interview was designed to answer all RQs including their sub-questions (See Figure 4-3).

4.4.2.2. Pilot Study of the Continuous PSTE

A pilot study was conducted to explore whether or not the research instruments serve the aim and answer the research questions. Pilot research is critical to determine possible weaknesses, deficiencies, vagueness and issues in all aspects of the research (Bryman 2012; Cohen et al. 2011; Teijling and Hundley 2001).
All research instruments of the continuous PSTE, which were introduced in Section 4.4.2.1, were pilot tested with four second-year PSTs over six weeks. Piloting this research helped the researcher to familiarise herself with the research environment and practice research in real situations before the main study began. Based on the outcomes of the pilot research, adjustments to the interviews and concept statement were made. Adjustments to the interview questions included changing, rewording or omitting some of the questions. These changes were made according to participants’ understandings of the terminology used, and therefore the terminology was adapted to participants’ levels. Additionally, a missing point to the concept statement was added. It was realised that participants did not include a budget calculation in their concept statement since it was not involved as part of what they had to include in the proposal. When the budget was assigned as an issue in the crisis management, participants realised what was missing. To prevent this issue, a budget was added as part of what they have to include in the proposal. After pilot testing all of the research instruments, the continuous PSTE data was collected.

4.4.2.3. Data Collection and Intervention: The Continuous PSTE

The research instruments have been applied for six weeks to the sample (n=3) in September and October after (1) the research instruments were developed, (2) sampling was decided upon, (3) the pilot research was conducted and (4) the research instruments were finalised. The data collection and intervention processes are summarised in Table 4.8.
Table 4.8: Continuous PSTE research instruments and the timeline of their use

<table>
<thead>
<tr>
<th>Research Instrument</th>
<th>Meeting Held</th>
<th>The Context of the Meeting</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-interview</td>
<td>The first week of September</td>
<td>Conducting interviews including a diagram construction</td>
<td>Around 40 minutes</td>
</tr>
<tr>
<td>Story-based group discussion</td>
<td>The first week of September</td>
<td>Applying the activity. Participants conduct a discussion on whether science is a social-institutional system based on the given story</td>
<td>46 minutes</td>
</tr>
<tr>
<td>Concept statement</td>
<td>The first week of September</td>
<td>Giving instruction sheets to participants about concept statement activity. Participants are given two weeks to come up with a science-related business idea and write a concept statement on this</td>
<td>15 minutes</td>
</tr>
<tr>
<td></td>
<td>The third week of September</td>
<td>Collecting participants’ two-page concept statements</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Focus group discussion</td>
<td>The third week of September</td>
<td>Conducting a focus group discussion on concept statements</td>
<td>30 minutes</td>
</tr>
<tr>
<td>Crisis management</td>
<td>The fourth week of September</td>
<td>Providing a report on the weaknesses of the concept statement and a problem causing a crisis in the business idea. Participants are given one week to solve the problem and write a report on it.</td>
<td>25 minutes</td>
</tr>
<tr>
<td>Post-interview</td>
<td>The first week of October</td>
<td>Collecting participants’ crisis management reports</td>
<td>5 minutes</td>
</tr>
<tr>
<td></td>
<td>The first week of October</td>
<td>Conducting interviews including a diagram construction</td>
<td>Around 50 minutes</td>
</tr>
</tbody>
</table>

The data collection process started with the application of pre-interviews in order to determine PSTs’ existing understandings of the social aspects of NOS and the relationship between state/government, academia, market and industry (the SAMI cycle framework\(^\text{16}\)). Then, the first intervention, the continuous PSTE, was started. During the intervention, the data were collected through the story-based group

\(^{16}\) Although the term “SAMI cycle framework” has been used throughout the thesis writing, the phrase “how science works in society” has been used during the data collection process. This is because (1) the SAMI cycle framework is an illustration of how science works in society, (2) participants do not have the background knowledge about the SAMI cycle framework and (3) using this phrase rather than the SAMI cycle framework can facilitate their understanding of the questions.
discussion, concept statement, focus group discussion and crisis management activities. All these research instruments were employed without any significant issue emerging. The researcher was involved without exposing her ideas when needed. For example, in the beginning, participants felt shy to start the discussion. Therefore, the researcher asked the first question and encouraged participants to discuss this question. After this, participants led their own discussion. Participants were told that they could contact the researcher anytime they need things, such as support, information, and clarification. The data collection was finalised by the application of the post-interviews to determine any changes in their understanding of the research topic.

4.4.3. Design of the Second Intervention and the Data Collection: The Once-off PSTE

This section introduces the once-off PSTE including the development of the research instruments, the pilot of the study and the data collection process. The once-off PSTE was defined as the involvement of learners in a one-time activity providing a snapshot of a given area to learn the given topic. During the once-off PSTE, an activity relating to the research topic was conducted with 50 PSTs (n = 50) for approximately two hours and aimed to answer RQ-1\textsuperscript{17} and RQ-2\textsuperscript{18}. The data was collected at four stages involving three research instruments in the once-off PSTE, which included qualitative and quantitative data collection instruments. This is because given the limited time and the large sample size, quantitative data was collected. Further data was collected by qualitative data collection instruments, which also allowed the researcher to have an in-depth understanding of the participants. The pre- and post-questionnaires consisted of the same questions. Therefore, three research instruments were developed for the once-off PSTE. These research instruments were introduced in Section 4.3.1.1 and Section 4.3.2.1, and their development process is explained in the next section.

\textsuperscript{17} RQ-1: How is PSTs' understanding of contemporary social aspects of NOS influenced by the research intervention?

\textsuperscript{18} RQ-2: How is PSTs' understanding of the relationship between state/government, academia, market and industry influenced by the research intervention?
4.4.3.1. Developing Instruments of the Once-off PSTE

In this section, the development of three data collection instruments for the once-off PSTE, which are related to the research aims and questions, are introduced. In the “once-off” aspect of the study, a questionnaire was administered as being a source of data at two time-points (before and after the intervention), and a role-play activity had the dual purpose of forming part of the intervention programme as well as being a source of data.

4.4.3.1.1. Questionnaire

As discussed and justified in Section 4.3.2.1, a five-point Likert scale questionnaire (See Appendix 11) including both open and closed questions was developed for the once-off PSTE. In this questionnaire, 30 statements were developed including relevant words from science and society, elements of SIS of science, and elements of the SAMI cycle framework. The last three questions were designed as open-ended questions. These open-ended questions were to determine participants’ opinion on the inclusion of entrepreneurship, EOS and the SAMI cycle framework into the JCSS and justification for their answer. In the development process, the interview questions which were used in the continuous PSTE were utilised to generate the statements for the questionnaire due to having the same aim. The questionnaire was pilot tested to produce reliable results. Further information about the pilot testing is presented in Section 4.4.3.2. The same questionnaire (pre-questionnaire) was applied at the end of the intervention (post-questionnaire) to compare participants’ understandings before and after the current study. The questionnaire investigated participants’ understandings of the social aspects of NOS (elements of SIS of science, entrepreneurship and EOS), the SAMI cycle framework and their place in the curriculum. Thus, it was designed to answer RQ-1 and RQ-2 including their sub-questions (See Figure 4-3).

4.4.3.1.2. Role-play Activity

The role-play activity was designed for third level students (university and college students) with a group of at least two students (Cohen et al. 2011). The entire activity consisted of seven parts. The first six parts were designed to be conducted
in groups, and the 7th part was an individual exercise. The development of these seven parts is summarised in the following paragraphs.

The first four parts of the activity (See Appendix 12) involve role-playing with a scenario on the discovery of the “Haber-Bosch Process”. These four parts include a scenario, role cards and question cards. In the development process of the activity, first of all, the scenario was designed based on a real science story, the discovery of the “Haber-Bosch Process”. An adaptation of this story was written according to the research aims by giving special attention to the inclusion of all elements of the SIS of science and the SAMI cycle framework, and this adaptation was used as the scenario in the activity. Secondly, the role cards (See Appendix 13) were developed. Thirdly, the story was divided into four parts coming from the four themes of the SAMI cycle framework (i.e. state/government, academia, market and industry). Each of those four parts had question cards, which were called “Question Time” (See Appendix 14), targeting different components of the SIS of science and the SAMI cycle framework (See Appendix 15 for further information). Therefore, the development of the first four parts of the activity was completed. The flow of these first four parts of the activity are summarised below:

1. All the characters take their role cards (roles are the storyteller, scientist 1, scientist 2, an entrepreneur, a person representing a company and a person representing the state)
2. A secretary is chosen within the group
3. Characters read their own parts according to the scenario
4. Secretary reads the “Question Time” cards
5. Group discussion is conducted on each question in the “Question Time”
6. Secretary takes notes and writes down the agreed answers

Part 5 (See Appendix 12) was developed to support students to understand the categorisation of the SAMI cycle framework. In this part, given the instructions and examples, participants were asked to fill the table by choosing some words from the story as well as using the words provided in a box. These words in the box were the same words with the ones provided in the diagram construction during the interviews. Part 6 (See Appendix 12) was developed to support students to understand how science works in society. In this part, giving the examples and
instructions, participants were asked to construct a diagram to explain how science works in society by utilising the table developed in Part 5. This diagram construction question was also used in the interviews in the continuous PSTE. Part 7 (See Appendix 12) was developed to collect more in-depth information on participants’ understanding of the role of entrepreneurship, EOS and the SAMI cycle framework in how science works in society. This part also aimed to triangulate the data by comparing the data collected in this part with the data collected from the questionnaires. Only this part was designed as an individual part involving three open-ended questions. The whole activity took approximately 75 minutes and was designed to answer only RQ-1 and RQ-2 (See Figure 4-3).

4.4.3.1.3. Interview

The same interview questions as used with the continuous PSTE were revised and prepared for use within the once-off intervention. The interview (See Appendix 16) included two parts: (1) PSTs’ experiences and (2) PSTs’ understanding of the four concepts (NOS, EOS, entrepreneurship and the SAMI cycle framework) and their educational views on the inclusion of these concepts into the JCSS. There were 12 questions, which were asked to all participants. Three questions targeted the first part while nine questions targeted the second part. Three additional questions were prepared to compare participants’ experiences of the continuous and once-off PSTE since two of the participants (Anne and Mary) were involved in both the continuous PSTE and once-off PSTE. This interview explored participants’ understandings of the social aspects of NOS (elements of SIS of science, entrepreneurship and EOS) and the SAMI cycle framework, and their place in the curriculum. Thus, it was designed to answer all RQs including their sub-questions (See Figure 4-3).

4.4.3.2. Pilot Study of the Once-off PSTE

A pilot study was conducted with the same aim with the continuous PSTE. The research instruments associated with the once-off PSTE, which are the questionnaire and role-play activity, were piloted in advance of use. Interview questions were not pilot tested again since they were piloted during the continuous PSTE. Piloting the current study helped the researcher to familiarise herself with the research environment and practice research in real situations before the main
study began. The objectives of piloting this part of the research are the same with the objectives of piloting the continuous PSTE\(^{19}\).

The questionnaire was pilot tested with 26 Master of Education students in the Education Department of a university in Ireland. Participants filled the questionnaire, and if they found anything unclear or problematic, they highlighted this and wrote some suggestions in the given space. Based on the feedback collected and following reflection on the administration process, some typical adjustments to the questionnaire were made including changing and rewording some statements. Furthermore, the negative sentences were replaced with positive sentences. For example, “there is no relationship between…” was replaced with “there is a relationship between…”. Next, the role-play activity was pilot tested with three PhD students: two from an Education Department and one from a Business School in a university in Ireland. During this pilot research, the flow of the scenario, timing, clarity of scenario, questions and instructions were checked. At the end of the activity, participants were encouraged to give some suggestions to improve the activity according to the third-year PST level. Participants were experts on adapting teaching levels of PSTs since they have been teaching at the university. Based on the feedback collected and following reflection on the process, adjustments were made to the role-play activity, including removing and rephrasing some of the questions on the Question Time cards. At the end of the activity, participants said that even though they were more mature than the target group they really enjoyed the activity and they could see the aim of the activity. After pilot testing all of the research instruments, the once-off PSTE data was collected.

4.4.3.3. Data Collection and Intervention: The Once-off PSTE

The research instruments were administered to the sample (n=50) in February after (1) the research instruments were developed, (2) sampling was decided upon, (3)

\(^{19}\) The objectives of piloting the continuous PSTE are (1) to determine deficiencies in the data collection instruments, (2) to test suitability of the data collection method, (3) to test whether or not it helps to answer the research questions, and (4) to increase the validity, reliability and overall effectiveness of the research instruments.
the pilot research was conducted and (4) the research instruments were finalised.
The completion of the once-off PSTE took approximately two hours. Before the
data collection, a class list was collected from the module lecturer and the location
of the class was identified. 56 PSTs including three PSTs, who attended the
continuous PSTE, were taking this module in a 100 seater tiered lecture theatre. In
order to omit the impact of these three PSTs, who were familiar with the aim of the
study, they were grouped together in Group J. The remainder of the students were
organised into nine groups from A to I. Each participant was given personalised
folders, and for each of the 10 groups, a group folder was prepared (See Appendix
17 for further information). Nine dictaphones were placed in each envelope and
assigned to the groups. Each group was given a predetermined location to sit during
the whole process. On the data collection day, the researcher arranged the room,
and the following occurred before the data collection process:

1. Personal folders and group folders were placed around the lecture hall.
2. Each group was placed around the lecture hall by calling the names of each
group members.
3. The role cards of the students, who did not show up, were assigned to the
others in the group by the researcher.
4. Students who volunteered to be a part of this research signed a consent
form.
5. Signed consent forms were collected by the researcher in a separate folder.

50 PSTs attended to the once-off PSTE. The data collection process started with
the administration of a pre-questionnaire to determine the participants’ existing
understanding of the social aspects of NOS and the relationship between
state/government, academia, market and industry (the SAMI cycle framework).
Then, the intervention started. During the intervention, the data was collected
through a role-play activity. The researcher was available to answer any questions.
Next, post-questionnaires were administered to determine the changes in
participants’ understandings of the research topic. The data collection was finalised
by interviewing three participants (Anne, Mary and Mark) to explore their
experiences of the continuous and once-off PSTE. Each participant was
interviewed for approximately 50 minutes.
4.5. DATA ANALYSIS

After collecting the qualitative and quantitative data, the data analysis process was started to determine emerging patterns and relationships from the data. By determining these patterns, themes and relationships, and inquiring the reason for their existence, data analysis transforms the collected data into “clear, understandable, insightful, [and] trustworthy” findings (Gibbs 2007, p.1). The data were analysed in three ways; thematic analysis, network analysis and quantitative data analysis. The rationales for utilising these methods and how these methods were applied are introduced in the following sections.

4.5.1. Thematic Analysis

Thematic analysis was used due to its prevalent use in analysing qualitative data, in particular, people’s perceptions and understanding (Braun and Clarke 2006; Bryman 2012; Creswell 2003; Gibbs 2007). Thematic analysis is “a method for identifying, analysing, and reporting patterns (themes) within data” (Braun and Clarke 2006, p.6). The phases of thematic analysis outlined by Braun and Clarke (2006) and inductive and deductive analysis explained by Fereday and Muir-Cochrane (2006) were utilised in this study. Deductive analysis was theory-driven, and EOS in NOS, Entrepreneurship in NOS and the SAMI cycle framework were the pre-determined themes due to the aim of the thesis. These themes were described based on Kaya et al.’s (2018). Inductive analysis was data driven and technology emerged from the data as one of the themes. Emerging themes and the processes are now outlined.

4.5.1.1. Phase 1

This phase was for the researcher to familiarise herself with the data. At the beginning of the qualitative data analysis, the verbal data collected throughout the current study were transcribed into word documents. In total, three pre- and three post-interviews of the continuous PSTE, and three interviews of the once-off PSTE have been transcribed. Through the process of transcription, the researcher started to familiarise herself with the data and developed a more thorough understanding of the data. The researcher further familiarised herself with the data by reading
through the transcripts repeatedly. To do this, the meanings and patterns were searched, and significant, reoccurring and interesting ideas were noted. This helped the researcher to familiarise herself with the depth and breadth of the content.

4.5.1.2. Phase 2

This phase included the process of generating initial codes and defining themes. Codes refer to:

the most basic segment, or element, of the raw data or information that can be assessed in a meaningful way regarding the phenomenon.  

(Boyatzis 1998, p.63)

In this process, a hybrid approach of inductive and deductive coding was adopted (Fereday and Muir-Cochrane 2006). This is because this study adopts both “data-driven” and “theory-driven” approaches in different parts. The relevance of “data-driven” and “theory-driven” approaches, the reasoning types and how these approaches were used in this study are exemplified in Figure 4-4.

![Figure 4-4: The approaches, the reasoning type adopted by these approaches and their examples in this study](image)

As part of the “theory-driven” approach, deductive coding was used. Deductive reasoning starts with a theory, a set of concepts or a conceptual scheme and logically demonstrates that a particular principle is valid. Therefore, pre-determined themes were used for categorising the coding. These pre-determined themes included the elements of the SIS in NOS defined by Erduran and Dagher (2014b). Descriptions of these elements and the key words used to define these
themes were brought together by Kaya and Erduran (2016) and presented in Table 4.9.

Table 4.9: SIS themes, and their descriptions and their defining key words

<table>
<thead>
<tr>
<th>THEMES</th>
<th>DESCRIPTION</th>
<th>KEY WORDS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professional Activities</td>
<td>How scientists engage in professional settings such as attending conferences and doing publication reviews</td>
<td>Conference, article, presentation, writing, publishing, publication</td>
</tr>
<tr>
<td>Scientific Ethos</td>
<td>The norms that scientists employ in their work as well as in interaction with colleagues</td>
<td>Scientific norms, ethics, bias, being sceptical, caution against bias</td>
</tr>
<tr>
<td>Social Certification And Dissemination</td>
<td>The social mechanism through scientists review, evaluate and validate scientific knowledge for instance through peer-review systems of journals</td>
<td>Peer-review, validate, evaluate, certification, dissemination, collaboration</td>
</tr>
<tr>
<td>Social Values Of Science</td>
<td>Values such as freedom, respect for the environment, and social utility</td>
<td>Culture, cultural, social values, society, beliefs, freedom, respect</td>
</tr>
<tr>
<td>Social Organisations And Interactions</td>
<td>How science is arranged in institutional settings such as universities and research institutes</td>
<td>University, research centre, institution, organisation</td>
</tr>
<tr>
<td>Political Power Structures</td>
<td>The dynamics of power that exist between scientists and within science cultures</td>
<td>Political power, research team, team leader, team members, researcher, nationality, gender, ethnicity, race</td>
</tr>
<tr>
<td>Financial Systems</td>
<td>The underlying financial dimension of science including funding mechanisms</td>
<td>Financial, funding, finance, economy, economical, budget</td>
</tr>
</tbody>
</table>

However, based on the current literature review and the proposed alternative way to the financial systems, the financial systems was re-described in Table 4.10. Additionally, Table 4.10 presents the descriptions of the contemporary social aspects of NOS, which are EOS and entrepreneurship, and the SAMI cycle framework due to the research focus and the RQs. These themes were explored and discussed in Chapter Two and Chapter Three, and based on this, their features are described concisely in Table 4.10.
Table 4.10: Additional themes used in the analysis and their descriptions

<table>
<thead>
<tr>
<th>THEMES</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economics of Science in NOS</td>
<td>The underlying economic dimension of science including funding mechanisms, commercialisation and commodification of science, and science and scientists in industry</td>
</tr>
<tr>
<td>Entrepreneurship in NOS</td>
<td>The underlying enterprising feature of science including scientific enterprise, entrepreneurial scientists, and creating job opportunities</td>
</tr>
<tr>
<td>The SAMI cycle framework</td>
<td>The relationship between state/government, academia, market and industry explaining how science works in society</td>
</tr>
</tbody>
</table>

Emerging sub-themes were recorded on separate word documents in each theme folder. Then, the codes and data extracts were re-visited and re-organised to clarify the overall themes and their aspects. Therefore, the selected codes and data extracts were justified. The refinements continued until they were not adding anything substantial, and the codes fitted the themes well. For example, during deductive coding, EOS and entrepreneurship related words and phrases were coded (See an example of data analysis in Appendix 18). When conducting this coding, Table 4.9 and Table 4.10 were utilised. Furthermore, the definitions and categorisation discussed in Chapter Two and Chapter Three informed this part of the analysis. In the pre-interviews of the continuous PSTE, when participants were asked about the relationship between economics and science, all participants emphasised that economics provide funding to science. *Funding of scientific research at academic institutions* was introduced as one of the scopes of EOS in Chapter Two, and funding mechanisms are introduced as one of the features of EOS in Table 4.10. Therefore, the theme “funding” emerged in Section 5.1.2.1 based on the pre-determined themes in Table 4.10.

As part of the “data-driven” approach, inductive coding was used. Inductive reasoning starts with observing specific cases and aims to develop a general principle from specific cases and observations. Within this context, the content of the entire data set was coded to determine whether there were new emerging codes.

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20 Creating job opportunities referred as career stage in Section 3.2.
Thus, the entire data set was worked through by giving equal attention to each data item. Interesting, significant, and reoccurring patterns were identified. A common criticism of coding is losing the context (Bryman 2012). Therefore, particular attention was paid to keep some surrounding relevant data to code extracts of data inclusively.

After initial coding and collating, the analysis focused on the broader level, which is combining different codes to form primary themes. At this part of the process, understanding and clarifying the relationships between codes, between themes and between codes and themes is of importance. After forming primary themes, the codes and data extracts were re-visited and re-organised to clarify, define and name the themes. For example, the data sets were re-read by the researcher after the deductive coding to inspect whether there was missing data. During the re-reading process of the data, the inductive coding process was employed. A result of inductive coding, the theme “economics, science and technology relationship” emerged in Section 5.1.2.1 since some participants mentioned this relationship as that economics is the driver of the technology or economics is required to provide the best technology for research. This theme was not referred to in the scopes of EOS nor Table 4.10. Therefore, this theme emerged as a result of inductive coding. Furthermore, in Section 5.2, there were no pre-determined themes but students predominantly mentioned understanding, knowledge and skills. Therefore, the data were categorised as understanding, knowledge and skills as a result of inductive coding (See Appendix 23 as an example). This coding process continued until the data saturation occurred (i.e. no new data was emerging).

4.5.1.3. Phase 3

This phase involved defining and naming themes. In this phase, the essence of each theme and the overall themes was identified, and the aspects of data covered by each theme were clarified. To do that, the codes and data extracts were re-visited and re-organised. This phase was applied to both inductive and deductive coding. The story of each theme, and how it completes the bigger picture and answers the RQs were considered.
4.5.1.4. Phase 4

When each theme was clearly defined and named the write-up process of results was started. During the writing of the results, attention was paid to write the results concisely and coherently. Also, the sense of what the theme was about, the interesting accounts of the data and how these themes form the story were presented. The results of the thematic analysis were used to answer RQ-1 and RQ-2 in Chapter Five and Chapter Six. The next section introduces another qualitative analysis method utilised in this study - network analysis.

4.5.2. Network Analysis

Network analysis is a mathematical analysis using algorithms and theories such as graph theory to model different types of networks (Brandes and Erlebach 2005; Borgatti et al. 2013; Hanneman and Riddle 2005). According to Peters-Burton (2012), NOS is a powerful framework for the use of network analysis.

> network analysis can be helpful in forwarding the study of views of the nature of science because of the technique’s ability to capture verbatim statements from participants and to display the strength of connections among the statements.

(Peters-Burton and Baynard 2013, p.2801)

That is, uncovering the way that connections between aspects of the NOS are understood may result in more effective ways of teaching and learning. As mentioned in Section 1.2.5.2, Peters-Burton (2012) also addressed that making more connections between NOS aspects referred to a higher understanding of NOS.

One of the data analysis method chosen to capture the co-occurrences of social aspects of NOS was network analysis (Hanneman and Riddle 2005). Co-occurrences were defined as instances which occurred during the interviews and represents two different aspects of NOS simultaneously. For example, a co-occurrence on “professional activities”, “scientific ethos”, “social certification and dissemination” and “social organisations and interactions” takes place when a participant states “attending conferences to share results with other scientists”. In this study, the network analysis was used as a method to develop information about the groupings and interconnections of specific data items since it uses the strengths
of the connections across a group to indicate the collective perceptions of the group (Peters-Burton 2012). Thus, network analysis was chosen to capture participants’ understanding of the relevance of the social aspects of NOS to each other and the relationship participants see between these different dimensions.

While interpreting results, there are certain evaluation criteria to make sense of the networks, such as centrality (Brandes and Erlebach 2005; Peters-Burton 2012, 2015; Peters-Burton and Baynard 2013; Peters-Burton et al. 2017; Rupp et al. 2009; Shaffer et al. 2009). Centrality, degree connectivity, closeness and density were employed in the current study to determine PSTs’ understanding of relevance and importance of the contemporary social aspects and the SAMI cycle framework (Peters-Burton 2012, 2015; Peters-Burton and Baynard 2013; Peters-Burton et al. 2017). Even though there is no certain definition of the centrality, it can be interpreted as among the other things or prestige. A centrality denotes an order of importance (Brandes and Erlebach 2005; Borgatti et al. 2013; Peters-Burton and Baynard 2013). Brandes and Erlebach (2005) explained the centrality with an example:

30 students in a classroom has to elect a class representative by voting one other student. In such situation “a student could be said to be the more ‘central’, the more people have voted for him or her” and this is called “in-degree centrality.

(Brandes and Erlebach 2005, p.18)

There are different metrics to define the significance of centrality; one of which is degree connectivity. Degree connectivity of a node is measured by looking at the total number of nodes it is connected to versus the total number of nodes it could possibly be connected to. Nodes are the variables in the study, which are the social aspects of NOS. For example, there are eight social aspects of NOS in this study, one of the eight being EOS. If EOS had connections with five other nodes in the pre-interview (5 out of 8) and with six other nodes in the post-interview (6 out of 8) it can be said that the degree connectivity of EOS to other social aspects of NOS has increased, and therefore its importance in relation to the other aspects has increased. However, this only provides information about the node in its local environment.
Another metric to define the significance of centrality is closeness. Closeness is defined as the reciprocal of the total distance (Brandes and Erlebach 2005; Kruskal 1964). Brandes and Erlebach (2005) explained the closeness with a simple example:

the focus lies here, for example, on measuring the closeness of a person to all other people in the network. People with a small total distance are considered as more important as those with a high total distance.

(Brandes and Erlebach 2005, p.22)

Thus, the central node has the lower distance to all other nodes, and the closeness represents the importance of a node compared to the other nodes in the group. To determine the closeness, Multi-Dimensional Scaling (MDS) was used. Multi-dimensional scaling is a statistical technique created to convert data indicating the degree of rated similarity or dissimilarity of data to scores indicating distances (closeness) among the objects (Peters-Burton 2015). That is, MDS interprets dissimilarities as distances on a graph. To do this, MDS uses a square symmetric matrix for input. The matrix shows the relationships between items. An example square symmetric matrix is provided in Table 4.11.

Table 4.11: A square symmetric matrix of A to E

<table>
<thead>
<tr>
<th>City</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>15</td>
<td>24</td>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>B</td>
<td>15</td>
<td>0</td>
<td>21</td>
<td>9</td>
<td>7</td>
</tr>
<tr>
<td>C</td>
<td>24</td>
<td>21</td>
<td>0</td>
<td>30</td>
<td>37</td>
</tr>
<tr>
<td>D</td>
<td>10</td>
<td>9</td>
<td>30</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>E</td>
<td>25</td>
<td>7</td>
<td>37</td>
<td>3</td>
<td>0</td>
</tr>
</tbody>
</table>

Through this matrix, MDS assigns points to coordinates in a two-dimensional space and calculates Euclidean distances for all pairs of points (Brandes and Erlebach 2005). The results engender the similarity matrix. Then, MDS compares the similarity matrix with the original input matrix by evaluating the stress function, which is the differences between predicted and actual distances (Hanneman and
Riddle 2005). The results are located on a map, and locations are assigned to nodes by UCINet software, which is a network analysis software. “More similar” nodes are located close together on the map (Brandes and Erlebach 2005). Then, the closeness is interpreted on the map according to their distance to each other. While the lower distance on the map represents the close relationships, the higher distance represents the distant relationship (Peters-Burton 2012, 2015; Peters-Burton and Baynard 2013; Peters-Burton et al. 2017). The density refers to the sum of ties/links which are divided by the number of possible ties/links (Hanneman and Riddle 2005). There are some mathematical results demonstrating that high density implies the other characteristics of cohesiveness, such as connectivity (Brandes and Erlebach 2005). Furthermore, Peters-Burton (2015) measured the average density based on the ratio of actual connections (edges between nodes) to possible connections to determine the connectedness between the nodes.

4.5.2.1. Outline and Steps of How Network Analysis were Applied in the Current Study

The network analysis was conducted through the UCI Net software. Due to the algorithms and the mathematical theories used in the network analysis software, the researcher bias in interpreting the data is considerably low. Network analysis was conducted to analyse the data on both the SAMI cycle framework and contemporary social aspects of NOS included in the SIS of science in NOS. The following steps present how network analysis was conducted in this study based on Brandes and Erlebach (2005), Hanneman and Riddle (2005), Peters-Burton (2012, 2015), Peters-Burton and Baynard (2013) and Peters-Burton et al. (2017). These steps exemplify the contemporary social aspects of NOS included in the SIS of science in Chapter 5. The same steps were applied during the to the SAMI cycle framework analysis in Chapter Six.

1. The audio records of the data were transcribed.
2. Eight social aspects of NOS\(^{21}\) were used as pre-defined themes. A square symmetrical matrix of the eight social aspects of NOS was developed similar to Table 4.11.

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\(^{21}\) Eight social aspects of NOS include two contemporary social aspects of NOS (i.e. EOS and entrepreneurship), and six components of SIS of science (i.e. professional activities, scientific ethos, social
3. The extraction of evidence began with reading the transcripts to make sense of the data.

4. The first analysis was conducted by categorising relevant statements of participants into eight pre-defined themes. For example, “funding” was categorised within “EOS in NOS” theme based on Table 4.10.

5. Transcripts were re-read, but this time special attention was paid to whether the statements represented more than one theme at the same time. The statements representing more than one theme were identified (co-occurrences). For example, when a participant states “attending conferences to share results with other scientists”, a co-occurrence on “professional activities” (PA), “scientific ethos” (SE), “social certification and dissemination” (SCD) and “social organisations and interactions” (SOI) takes place. This categorisation was theoretically influenced by Section 2.1.2.1 and Section 3.2. This process was repeated until no new relationship was determined and each process was conducted for each interviewee individually.

6. When the co-occurrences were determined, these co-occurrences were coded into the square symmetrical matrix table (See Appendix 19 for an example network analysis table). During this process, for example, if “attending conferences to share results with other scientists” was coded as a co-occurrence in the intersection of “professional activities” and “scientific ethos” (PAxSE), this co-occurrence was also placed in the intersection of “scientific ethos” and “professional activities” (SExPA).

7. When a participant only described one aspect of NOS, this was not added to the cross-correlation table since a co-occurrence did not take place (singular occurrence).

8. Co-occurrences of eight social aspects of the NOS were identified and tallied for all participants interviewed (See Appendix 19 for an example network analysis table). Thus, the frequencies of co-occurrences of eight social aspects were translated into the square symmetrical matrix table for the pre and post interviews of each participant. The symmetric matrix facilitates checking the accuracy of the data entry. In Table 4.12, the square
symmetrical matrix table of Anne’s post-interview in the continuous PSTE is presented as an example.

Table 4.12: Anne's square symmetrical matrix table of the post-interview in the continuous PSTE

<table>
<thead>
<tr>
<th>Social Aspects of NOS</th>
<th>Professional Activities (PA)</th>
<th>Scientific Ethos (SE)</th>
<th>Social Values of Science (SVS)</th>
<th>Social Certification and Dissemination (SCD)</th>
<th>Social Organisations and Interactions (SOI)</th>
<th>Political Power Structures (PPS)</th>
<th>Economics of Science (EOS)</th>
<th>Entrepreneurship (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Professional Activities (PA)</td>
<td>0</td>
<td>5</td>
<td>0</td>
<td>7</td>
<td>8</td>
<td>2</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Scientific Ethos (SE)</td>
<td>5</td>
<td>11</td>
<td>20</td>
<td>25</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Social Values of Science (SVS)</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Social Certification and Dissemination (SCD)</td>
<td>7</td>
<td>20</td>
<td>3</td>
<td>0</td>
<td>26</td>
<td>5</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>Social Organisations and Interactions (SOI)</td>
<td>8</td>
<td>25</td>
<td>5</td>
<td>25</td>
<td>0</td>
<td>8</td>
<td>23</td>
<td>18</td>
</tr>
<tr>
<td>Political Power Structures (PPS)</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>8</td>
<td>0</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Economics of Science (EOS)</td>
<td>7</td>
<td>7</td>
<td>2</td>
<td>12</td>
<td>22</td>
<td>7</td>
<td>0</td>
<td>21</td>
</tr>
<tr>
<td>Entrepreneurship (E)</td>
<td>5</td>
<td>5</td>
<td>3</td>
<td>10</td>
<td>17</td>
<td>7</td>
<td>21</td>
<td>0</td>
</tr>
</tbody>
</table>

9. The completed symmetrical matrix table was uploaded to the network analysis software, UCI Net, to analyse the strength of connections between statements within the node (or point) clusters (in this case the nodes are eight social aspects).

10. By using “net draw” in UCI Net, maps (diagrams) representing the participants’ view on the relationship between social aspects of NOS were created. In these maps, the nodes are representing the social aspects of NOS, and the links between the nodes illustrate how participants see the importance and interconnectedness of these aspects (Peters-Burton 2012; Rupp et al. 2009; Shaffer et al. 2009).
11. Degree connectivity was determined according to the number of connections/links/ties between the nodes on the network analysis map. For example, if there were two links in total, which are EOS and professional activities link and entrepreneurship and EOS link, the degree connectivity was counted as two (n = 2).

12. The centrality was mainly determined according to the betweenness of the nodes in the network analysis map.

13. To determine density, the symmetrical matrix table was uploaded to the UCI Net, and the density measure was run. The result is also compared with the network analysis map.

14. Closeness was determined according to the distance between the nodes.

When interpreting the degree of closeness\textsuperscript{22} in the network analysis map, even though terms “close, very close, distant, very distant” are used in the literature (Peters-Burton 2012, 2015; Peters-Burton and Baynard 2013; Peters-Burton et al. 2017) no study came up after an extensive search of the literature, specifically defining how the degree of closeness was calculated. However, closeness is a relativistic concept, and it changes depending on the scale. For example, 100 km is distant if the scale is 110 km; however, it is close if the scale is 1000 km. Since the scaling is different for different studies, the degree of closeness was defined according to the scaling in this study. In scaling in different disciplines, interval width is calculated by subtracting min from max and dividing this by the number of intervals, which means:

\[
    w = \text{interval width} = \frac{\text{largest value} - \text{smallest value}}{\text{number of desired intervals}}
\]

This equation is mathematically represented as:

\[
    w = \frac{R}{n} = \frac{X_{\text{max}} - X_{\text{min}}}{n}
\]

(Newbold et al. 2012)

\textsuperscript{22} Closeness of the nodes was already allocated through MDS by UCI Net software. Here, to what extent the nodes are close is identified from the map.
Based on this context, when the network analysis maps (diagrams) representing the relationship between different nodes were created, the longest and shortest distances between the nodes were determined. The number of intervals was defined as four (very close, close, distant, very distant) based on the literature (Peters-Burton 2012, 2015; Peters-Burton and Baynard 2013; Peters-Burton et al. 2017). Therefore, the shortest distance was subtracted from the longest distance, and the result was divided into four. For example, when the network analysis maps of the social aspects of NOS were created through the UCI Net, the longest distance was 26 cm, and the shortest distance was 2.9 cm between the nodes on the network analysis map. Thus:

\[ w = \frac{26 - 2.9}{4} = 5.775 \text{ cm} \]

5.78 cm was determined as the interval width representing the degree of closeness. Therefore, for the social aspects of NOS, the distances were represented as follows, where “\( t \)” represents the link between the nodes:

- \( 2.9 \text{ cm} < t \leq 8.675 \text{ cm} \) => very close relationship
- \( 8.675 \text{ cm} < t \leq 14.45 \text{ cm} \) => close relationship
- \( 14.45 \text{ cm} < t \leq 20.225 \text{ cm} \) => distant relationship
- \( 20.225 \text{ cm} < t \leq 26 \text{ cm} \) => very distant relationship

The interval width also determined for the SAMI cycle framework network analysis maps. The longest distance in these maps was 29.8 cm, and the shortest distance was 3 cm between the nodes on the network analysis map.

Thus:

\[ w = \frac{29.8 - 3}{4} = 6.7 \text{ cm} \]
6.7 cm was determined as the interval width representing the degree of closeness. Therefore, for the SAMI cycle framework, the distances were represented as follows, where “t” represents the link between the nodes:

- 3 cm < t ≤ 9.7 cm => very close relationship
- 9.7 cm < t ≤ 16.4 cm => close relationship
- 16.4 cm < t ≤ 23.1 cm => distant relationship
- 23.1 cm < t ≤ 29.8 cm => very distant relationship

Therefore, the implementation and interpretation of the network analysis were completed. The results of the network analysis were used to answer RQ-1 and RQ-2. In the next section, the quantitative data analysis is explained.

4.5.3. Quantitative Data Analysis

This section explains how the quantitative data were analysed. During the quantitative analysis, questionnaires were analysed using the Statistical Package for the Social Sciences (SPSS) software which is a quantitative data analysis tool. However, there are many different statistical tests, and there are different factors affecting the decision of which statistical test to employ, such as the purpose of analysis, the kinds of data (parametric and non-parametric), the scales of data (nominal, ordinal, interval, ratio), the number of groups in the sample, the assumption in the test, whether the samples are independent of or related to each other (Cohen et al. 2011). Therefore, these factors are summarised to justify the choice of the statistical test.

1. The aim and the group size: Pre- and post-questionnaires were applied to 50 participants to measure their views regarding the concepts before and after the intervention, thus to determine whether there was a significant change in participants’ understanding. Therefore, quantitative analysis findings contribute to answer RQ-1, RQ-2 and their sub-questions (RQ-1.1 and RQ-2.1) and triangulate the data.

2. The data scale: The data was determined to be ordinal data due to the use of a Likert scale in the questionnaires. Ordinal refers to quantities with a natural ordering (Laerd Statistics 2013; Vogt 2007). In an ordinal scale,
there is no certainty whether the intervals between each value are equal. For example, on a five-point Likert scale, the difference between 1 and 2 is not necessarily the same with the difference between 3 and 4 (Creswell 2003; Vogt 2007).

3. The data type: The data is non-parametric, i.e. the data is not required to be normally distributed (Laerd Statistics 2013). Non-parametric statistics are chosen due to the data being ordinal which means it does not rely on numbers but rather relies on ranking.

4. The number of groups and the relevance of samples: Two related samples (matched samples), which were pre- and post-test scores of the same group of PSTs, were used in this study.

After identifying each of the four factors, the questionnaires were coded from one to five increasingly (Strongly Disagree = 1, Strongly Agree = 5) into the data files. However, there were some items which had to be reverse coded, which means that these items were coded on the other way around (Strongly Disagree = 5, Strongly Agree = 1). For example, the 4th statement in the questionnaire is “scientists conduct only scientific investigations”, which is related to professional activities. Since scientists also perform professional activities, such as attending conferences as well as conducting investigations, this statement was reverse coded (Laerd Statistics 2013).

After setting up the data files, the type of statistical analysis test is decided before starting to analyse the data. Based on the identified four factors above, the statistical analysis test of the questionnaires was determined as Wilcoxon signed-rank test (Wilcoxon matched pairs test). However, there are three assumptions required for a Wilcoxon signed-rank test to give a valid result. According to Laerd Statistics (2013), these assumptions are:

- The first assumption: The dependent variable should be measured at the ordinal or continuous level. As mentioned within the four factors above, the data is ordinal. Therefore, this assumption is fulfilled.
- The second assumption: The independent variable (i.e. the paired observations are randomly and independently drawn) should consist of two categorical, related groups or matched pairs. As mentioned within the four
factors above, the data are two-related samples (matched samples). Therefore, this assumption is fulfilled.

- The third assumption: The data have to be normally distributed. However, as mentioned within the four factors above, the data is non-parametric. Therefore, the normal distribution is not required.

Thus, the Wilcoxon signed-rank test was chosen, and all quantitative data were analysed by using this test. A summative score was created to summarise the 30 pre and 30 post-questionnaire statements. Next, the data were categorised and re-coded into different variables. For example, 12th, 21st, 23rd and 24th statements in the questionnaire were categorised together as EOS, and these categories’ summative pre-questionnaire score, summative post-questionnaire score and difference between these scores were coded into different variables. The category name, the statement numbers included in this category and which scores were calculated are presented in Table 4.13.

Table 4.13: Categorised data with details including the name of, the statement numbers included in and the calculated scores of the category

<table>
<thead>
<tr>
<th>Name of the category</th>
<th>Statement Number Included in the Category</th>
<th>Calculated Scores for the Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>SIS</td>
<td>1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 14, 15, 17, 18</td>
<td></td>
</tr>
<tr>
<td>Science and Society</td>
<td>1, 2, 3</td>
<td></td>
</tr>
<tr>
<td>Professional Activities</td>
<td>4, 6</td>
<td></td>
</tr>
<tr>
<td>Scientific Ethos</td>
<td>11, 14</td>
<td></td>
</tr>
<tr>
<td>Social Certification and Dissemination</td>
<td>7, 8</td>
<td></td>
</tr>
<tr>
<td>Social Values of Science</td>
<td>9, 15</td>
<td></td>
</tr>
<tr>
<td>Social Organisations and Interactions</td>
<td>5, 10</td>
<td><img src="image1" alt="Pre-questionnaire summative score" /> <img src="image2" alt="Post-questionnaire summative score" /> <img src="image3" alt="Difference between pre- and post-questionnaire summative scores" /></td>
</tr>
<tr>
<td>Political Power Structure</td>
<td>17, 18, 19</td>
<td></td>
</tr>
<tr>
<td>Economics of Science</td>
<td>12, 21, 23, 24</td>
<td></td>
</tr>
<tr>
<td>Entrepreneurship</td>
<td>22, 26, 27</td>
<td></td>
</tr>
<tr>
<td>The SAMI cycle framework</td>
<td>4, 5, 10, 13, 16, 19, 20, 23, 24, 25, 27, 28, 29, 30</td>
<td><img src="image1" alt="Pre-questionnaire summative score" /> <img src="image2" alt="Post-questionnaire summative score" /> <img src="image3" alt="Difference between pre- and post-questionnaire summative scores" /></td>
</tr>
</tbody>
</table>
Based on the categorisation and its details presented in Table 4.13, all the data was analysed. Within this context, frequency and mean of each question were outlined to interpret the data and presented in Appendix 25. Appendix 25 was utilised in Chapter Five and Chapter Six to determine the changes in PSTs’ understanding of particular categories, which were mentioned in Table 4.13.

Before conducting the quantitative analysis, the hypotheses were determined. Hypotheses are the statements designating what the researcher expects to find and derived from the observations and facts described in the research questions (Birdthistle 2004). Therefore, the research questions and the hypothesis of each question are presented.

**RQ-1: How is PSTs’ understanding of contemporary social aspects of NOS influenced by the research intervention?**

*Null Hypothesis*=

\[ H_0: \text{There is no significant difference in the mean rank of PSTs’ understanding of contemporary social aspects of NOS before and after the research intervention.} \]

*Alternative Hypothesis*=

\[ H_a: \text{There is a significant difference in the mean rank of PSTs’ understanding of contemporary social aspects of NOS before and after the research intervention.} \]

When the “p number” is smaller than .05 (p < 0.05), the null hypothesis is rejected, and the alternative hypothesis is accepted. RQ-1 is investigated in two parts since contemporary social aspects of NOS include EOS and entrepreneurship. Therefore, two sub-hypotheses were written to answer this question.

*Null Hypothesis*=

\[ H_{01}: \text{There is no significant difference in the mean rank of PSTs’ understanding of EOS before and after the research intervention.} \]
Alternative Hypothesis=

\( H_{a1}: \) There is a significant difference in the mean rank of PSTs’ understanding of EOS before and after the research intervention.

To examine this hypothesis, as mentioned previously, the relevant statements in the questionnaire (See Table 4.13) were categorised together as EOS. This category’s summative pre-questionnaire score, summative post-questionnaire score and difference between these scores were coded into different variables. Then, the data were analysed by the Wilcoxon signed-rank test. The same process has been followed for the other hypotheses.

Null Hypothesis=

\( H_{02}: \) There is no significant difference in the mean rank of PSTs’ understanding of entrepreneurship before and after the research intervention.

Alternative Hypothesis=

\( H_{a2}: \) There is a significant difference in the mean rank of PSTs’ understanding of entrepreneurship before and after the research intervention.

RQ-2: How is PSTs’ understanding of the relationship between state/government, academia, market and industry influenced by the research intervention?

Null Hypothesis=

\( H_{03}: \) There is no significant difference in the mean rank of PSTs’ understanding of the relationship between state/government, academia, market and industry (the SAMI cycle framework) before and after the research intervention.
Alternative Hypothesis =

\[ H_{a3} : \text{There is a significant difference in the mean rank of PSTs’ understanding of the relationship between state/government, academia, market and industry (the SAMI cycle framework) before and after the research intervention.} \]

To examine this hypothesis, as mentioned previously, the relevant statements in the questionnaire (See Table 4.13) were categorised together as the SAMI cycle framework. This category’s summative scores and the difference between these scores were coded into different variables. Then, the data were analysed by the Wilcoxon signed-rank test. In the results, when the “p number” is smaller than .05 (\( p < 0.05 \)) the null hypothesis is rejected, and the alternative hypothesis is accepted.

### 4.6. RELIABILITY AND VALIDITY OF THE STUDY

In conducting research - qualitative and/or quantitative-, it is unavoidable that the researcher influences the participant and therefore the data even if it is only a slight influence (Cohen et al. 2011). Thus, the researcher must ask how this influence can be minimised and how the accurate presentation of the observations and measurements can be ensured (Wellington 2003). That is, the responsibility of the researcher is to ensure the validity and reliability of the research.

Briefly, validity is concerned with whether research instruments do what they say they do, and the research instruments measure what it claims they measured. In the current study, internal and external validity was assessed. Reliability is concerned with the precision and accuracy of the research method and the replicability of the research. According to Diamantopoulos and Schlegelmilch (2000) and Cohen et al. (2011), a valid measure is reliable; however, a reliable measure may or may not be valid. Thus, the reliability of the study is discussed before addressing the validity issues. Overall, by portraying and proving the validity and reliability of the research, trustworthiness of the research results and theories produced by this study are clarified. Thus, the reliability and validity of this study are discussed below.
4.6.1. Reliability

Reliability refers to the dependability, consistency and replicability of the research over time under similar conditions, such as a similar group of respondents in a similar research context (Bell 2010; Cohen et al. 2011). To increase reliability, the researcher should question whether the research will provide similar results when repeated by different researchers (Vogt 2007). Even though finding similar results is important in quantitative research, it is not always feasible or desirable for qualitative studies. The measures taken to ensure the reliability of the current study are now outlined.

There are a number of points emphasised by Denzin and Lincoln (2000) and Cohen et al. (2011) to increase the reliability of the qualitative part of the research and prevent bias. In the current study:

- The researcher did not select the participants and therefore did not affect the sampling process as participants volunteered. That is, the researcher bias to choose the sample was avoided, and thus the sample is reliable.
- This study does not aim to be generalised. Instead, the current study focuses on the experiences and understandings of a specific group. Therefore, generalisation is not an issue and does not affect the reliability of this study.
- “Thick description” was used to overcome reliability issues. For this purpose, the necessary and essential aspects of the study, including data collection and analysis, were described in detail. Therefore, the possibility of other researchers collecting data within the original research design was also increased.
- The data were collected with different research tools. That is, both qualitative and quantitative data have been collected through the use of different research instruments (See the research tools used in this study in Figure 4-2).
- Triangulation was used in the current study (See Section 4.3.3. for further details). Triangulation refers to the application of different methods on the same phenomenon to come up with an answer Denzin and Lincoln (2000). Therefore, triangulation decreases the bias and increases the reliability. Triangulation is also important to the research for adding “breadth or depth”
to research analysis (Fielding and Fielding 1986). In the current study, triangulation was applied in terms of participants, research instruments and data analysis. In this sense, by meeting different participants at different times, the participants were triangulated. By using the same research instruments to answer the same question, the research instruments were triangulated. For example, both the story-based group discussion and concept statement aimed to answer RQ-1 and RQ-2. By using different data analysis type to analyse the same data, the analysis was triangulated. For example, the same data was analysed through both thematic analysis and network analysis.

- During the interview, the researcher sought approval on whether she correctly understood what the participant was saying. For example, she asked “If I understand truly you mean…?” By doing so, the researcher bias was decreased, and thus reliability was increased.

- The adequate rapport between the researcher and the participants was provided. For instance, to make the participants feel comfortable and sincere, the researcher had a general short conversation out of the research context with the participants. Thus, the reliability was increased since participants give more sincere answers when they feel more comfortable in the research environment.

- In the entire data, attention was paid to collecting the data extracts within their context. This is because during the coding process if the data extracts were collected without giving the context, the data may not make sense in the analysis and may fail to tell the story of the study (Braun and Clarke 2006).

To increase and assess the reliability of the quantitative part of the current study, Cronbach’s Alpha was used to estimate the reliability and internal consistency of the multi-item constructs of the questionnaire. Cronbach Alpha is a commonly used statistical test to determine the reliability of research (Vogt 2007) and the correlation of each item and the correlation between the items (Tavakol and Dennick 2011). The higher Alpha represents a more reliable test. There is different acceptance of the value of internal reliability ranging from 0.70 to 0.95. For example, although Vogt (2007) accepts an Alpha of 0.70 as satisfactory, Tavakol and Dennick (2011) support a maximum Alpha value of 0.90 as acceptable. The
results of Cronbach Alpha employed in the current study are presented in Figure 4-5.

![Cronbach's Alpha](image)

Figure 4-5: Cronbach's alpha reliability statistics

As seen in Figure 4-5, Alpha value is .702 (> .70). Thus, this questionnaire was determined as reliable. In addition to internal reliability, the reliability of data sources was also evaluated. The questionnaire was developed by going through many revisions through five experts and piloting the study. Throughout the process, several rounds of questionnaires were sent out to the experts, and the revised version of the questionnaire was shared with the experts after each round. Additionally, an expert working at the statistical unit at the University of Limerick reviewed the questionnaire and the interview sheets and provided feedback to the researcher.

### 4.6.2. Validity

Validity refers to whether a set of operations measure what it is supposed to measure (Bohrnstedt 1983). Therefore, trustworthiness is important for research. In order to show the trustworthiness of the research including its results and conclusions, the researcher needs to ensure the validity of the research. Validity is also related to whether a study can be generalised across different social setting. Validity is a requirement for both qualitative and quantitative research; however, it might be accepted as a degree of cogency rather than being accepted as absolute truth. In this sub-section, how qualitative and quantitative validity was increased in this study is explained subsequently.
In qualitative data, validity might be provided by:

the honesty, depth, richness and scope of the data achieved, the participants approached, the extent of triangulation and the disinterestedness or objectivity of the researcher.

(Winter 2000 in Cohen et al. 2011, p. 179)

In this study, two main types of validity were applied; internal and external validity. Internal validity is to explain whether a particular event, issue or a set of data provided by the research can be sustained by the data (Cohen et al. 2011). In both qualitative and quantitative parts of the current study, internal validity was increased by adopting the points addressed by Lincoln and Guba (1985), such as having a long-term engagement in the research topic, applying triangulation of methods and member checking, and reducing researcher bias. The depth and richness of the data were provided by collecting both qualitative and quantitative data through different research instruments, such as concept statement activities, interviews and questionnaires. The clarity and comprehensibility of the research instruments were increased by conducting pilot studies (See Section 4.4.2.2 and 4.4.3.2). Honesty and attitude of the participants were ensured by their attitude to be willing to work with the researcher, and their detailed responses to the questions asked verbally or written throughout the current study. Finally, the bias in the current study was reduced by asking control questions, such as “If I understand truly you mean…, do you?”, crosschecking with additional questions and by paying attention so as not to affect participants’ responses as a researcher, i.e. not providing explanations unless clarification was needed.

External validity is explored separately in qualitative and quantitative parts of the current study.

In the qualitative part of this study, external validity was interpreted as comparability and transferability (Lincoln and Guba 1985). As part of the external validity, content validity and construct validity were explored. Content validity is a subjective assessment of whether the content is appropriate and it covers the domain or items that it purports to cover (Carmines and Zeller 1979; Diamantopoulos and Schlegelmilch 2000). To increase the content validity, (1) the literature has been reviewed to identify how the concepts in the current study were used by other researchers, (2) three experts’ opinion was considered with relevant
changes being made, and (3) the instruments were piloted with university students with similar backgrounds. In the pilot study, participants’ opinion was asked whether the research instruments were suitable for the given purpose and if they were clear and comprehensible.

Construct validity is to measure theoretically how meaningful a survey instrument is (Diamantopoulos and Schlegelmilch 2000). That is, it refers to the extent to which a research instrument captures a specific theoretical framework and its aspects. In this study, construct validity was increased according to the research conducted by Cohen et al. (2011) and Teijlingen and Hundley (2001). Within this purpose, to increase construct validity, (1) the construct and structure of the questions were defined carefully, (2) existence of the phenomenon being measured was demonstrated through the literature review, (3) the research instruments were piloted, (4) the meaningfulness of the categories used by the researcher to the participants was presented through the findings, and (5) the relationship between research findings was explained.

In quantitative data, validity can be increased by careful sample selection, using appropriate instruments for the research aims and using appropriate statistical measurements. Ensuring validity also requires:

being faithful to the assumptions underpinning the statistics used, the construct and content validity of the measures used, the careful sampling, the avoidance of a range of threats to internal and external validity.

(Cohen et al. 2011, p.180)

In the quantitative part of the study, internal validity was increased in the same way with qualitative data. Concerning the external validity, the content validity and construct validity were applied in the quantitative part of the study. Content and construct validity were explained in the previous paragraph. To increase the content validity of the questionnaire based on Bohrnstedt (1983) and Diamantopoulos and Schlegelmilch (2000), firstly, the concepts and constructs were defined based on the literature review on developing and applying a questionnaire. These concepts were SIS of science and the SAMI cycle framework. Secondly, these concepts were divided into their main facets based on the literature, and different facets were defined where possible. For example, the main facets were defined as six elements
of the SIS of science, two elements of contemporary social aspects of NOS and the elements of the SAMI cycle framework. Thirdly, the questionnaire was piloted (Bohrnstedt 1983).

The construct validity was increased in the same way with the qualitative part of the study according to the research conducted by Cohen et al. (2011) and Teijlingen and Hundley (2001). Additionally, to increase the construct validity of this study, questionnaire items and their constructs were carefully defined in relation to the literature and correlation coefficient between variables was examined (Bohrnstedt 1983; Carmines and Zeller 1979). The correlation coefficient is a measure of the strength of a linear association between two variables (Balnaves and Caputi 2001). While the correlation between 0.60 and 0.85 shows a relationship between variables, the correlation above 0.85 indicates a very strong relationship and correlation below 0.60 does not point to any significant relationship between variables (Cohen et al. 2011). Normality is an important assumption in the testing correlation coefficient (Laerd Statistics 2013). The normality of the data tested and Sig.=.051 (<.05) which shows that the data was normally distributed (See Appendix 20).

Furthermore, as mentioned in Table 4.13, the data were categorised such as those related to the SAMI cycle framework, SIS of science, and social aspects of NOS. Thus, the correlation coefficient was tested between these categories, in particular, overall score (named pre or post), the SAMI cycle framework (named SAMI) score and social aspects of NOS (named socialNOS) score. A strong relationship (.7 ≤ correlation ≤ .9) between overall score and social aspect of NOS, and between overall score and SAMI was found in the pre-test (See Appendix 21). There was a moderately strong relationship (.6 ≤ correlation < .7) between the social aspect of NOS and SAMI. To validate the results, the correlation coefficient in post-test was also checked. There was a strong relationship (.7 ≤ correlation ≤ .9) between overall score and social aspect of NOS, and between overall score and SAMI was found in the post-test (See Appendix 22). There was a relationship between the social aspects of NOS and the SAMI cycle framework (correlation = .596).

It was claimed that this questionnaire was developed based on social aspects of NOS and SAMI cycle framework, and these correlations are also supporting this
claim. Thus, the construct validity was provided. Overall, the validity of the research instruments was enhanced by using relevant literature and appropriate statistical measurements; providing feedback and revisions through five experts; and piloting the study. Furthermore, replicability of the current study was increased by using “thick description”. Therefore, the validity was increased, the researcher bias was decreased, and the value of conclusions was strengthened.

4.7. ETHICAL CONSIDERATIONS

From the beginning of the current study, the researcher was aware of her responsibility to:

  take into account the effects of the research on participants, and act in such a way as to preserve their dignity as human beings.

(Cohen et al. 2011, p.84)

The researcher completed a research ethics module and discussed the possible ethical issues with colleagues and supervisors. By taking the outcomes of these discussions into account and by following the ethical guidelines of the University of Limerick, the researcher applied for ethical approval for the study. Research ethics was granted by the Research Ethics Committee of the University of Limerick. Recommendations of the committee were taken on board.

The ethical issues considered in the study were the age of students, anonymity, confidentiality, voluntariness and withdrawal right from the study. What should be done to overcome each of these issues was considered. Participants were PSTs, who were over 18 years old, and therefore child protection procedures were disregarded. The anonymity of the participants was provided by using fake names and codes such as P1 and P2. Concerning confidentiality, the data was not shared with anyone other than the researcher and the supervisors. Furthermore, all collected data was stored securely until the time the PhD degree is successfully completed. After waiting for an adequate time following the completion of the current study, all the data will be deleted.
By providing the research information form and the consent form given to the participants, anonymity, confidentiality, voluntariness and their withdrawal right from the study were ensured. These forms included information about the aim of the study, the research process, participants’ rights, anonymity and confidentiality in the study. Attempts were to make sure that the participants understood that their participation in this study was voluntary-based, there was no right or wrong answer and participation would not be linked to grades. When participants wanted to leave the study, they had the right to withdraw from the study without question. Therefore, participants received a consent form prior to taking part in the study and also were able to withdraw at any time. After making sure that attendance was voluntary and it would not affect their grades, volunteered PSTs signed the consent form and became participants. Additionally, to participate in an interview at the end of once-off PSTE, a tick box was included at the end of the post-questionnaire to invite the participants to take part in a further interview which will be organised in the next two weeks according to volunteers’ schedule.

The researcher ensured that all aspects of the current study (interviews, questionnaires and activities) were conducted in an ethical manner throughout the research, for instance, it was ensured that all participants were provided with enough information about the study. The contact details of the researcher and an external contact were also provided in case they had any queries relating to the study.

4.8. LIMITATIONS OF THE STUDY

In this section, the researcher highlights the main limitations of the current study.

Considering the number of PSTs attended the continuous PSTE, the duration of the study and the fact that PSTs were attending this research as an extra to their teacher education programme might have put some students off participating in the current study (Guerin 2017). This might be because pre-service teacher programmes are very busy with different agendas, as discussed in Chapter One. Furthermore, the small sample size of the continuous PSTE (n=3) affected the choice of data analysis and the extent to which generalisations can be drawn from the data.
Regarding the once-off PSTE, due to employing the same questionnaire at the beginning and the end of the current study, the majority of students did not respond the open-ended questions in the questionnaire that were applied at the end of the once-off PSTE. Furthermore, there were 10 groups (n=50) in the module that the once-off PSTE was conducted, but it was not possible to assign an instructor to each group. Each group had their own pace, and therefore they finished the role-play activity at different times. This may have resulted in distractions of participants’ motivation.

Questionnaires were not anonymous at the time the data was collected. This may be another limitation of the study. However, before the data was analysed, the questionnaires were anonymised by giving numbers and names to participants. Therefore, attempts were made to accommodate for this limitation.

The current study was conducted at only one university in Ireland. Working with a specific group might have affected the generalisability of the research results.

4.9. CONCLUSION

In this chapter, the research aim, the research questions and the paradigm of the study were clarified. The continuous and once-off PSTE were introduced within the research design, and the research samples were identified as three participants in the continuous PSTE, 50 participants in the once-off PSTE. The current study was designed to actualise the research objectives and answer the research questions. Therefore, activities were developed and applied to enhance PSTs’ understanding on the role of EOS and entrepreneurship in NOS, and the SAMI cycle framework as well as the interviews and the questionnaire to identify the PSTs’ understanding. These activities can be used for science teaching and learning. After identifying the data collection procedure, the data was collected and analysed. Thematic analysis, network analysis and quantitative analysis were conducted. While UCI Net software was utilised to perform network analysis, the quantitative part of the questionnaire was analysed through SPSS. Additionally, the reliability and validity of the study and the ethical considerations were discussed.
After discussing what the current study is about in the first three chapters, how the study was conducted, and the data were analysed were discussed in Chapter Four. The findings of the study are presented in Chapter Five and Chapter Six. The findings related to RQ-1 and RQ-1.1 are presented in the next chapter – Chapter Five.
CHAPTER FIVE: CONTEMPORARY SOCIAL ASPECTS OF NOS AND THEIR ROLE IN THE JCSS

EOS and entrepreneurship were introduced as the contemporary social aspects of NOS in Chapters Three, at which time the benefits and importance of these concepts were discussed. This section presents the results relating to the contemporary social aspects of NOS and aims to answer the research questions RQ-1 and RQ-1.1. To answer these research questions, the thematic analysis, network analysis and the Wilcoxon signed-rank test were utilised. Throughout the section, the results from the continuous PSTE are firstly presented, followed by the once-off PSTE. The participants’ involvement in the various aspects of the study is outlined in Table 5.1.

Table 5.1: Participants and the PSTE type and part that these participants engaged

<table>
<thead>
<tr>
<th>Type of PSTE</th>
<th>Continuous PSTE including activities and interviews (n = 3)</th>
<th>Once-off PSTE including questionnaires and the role-play activity (n = 50)</th>
<th>Once-off PSTE interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants</td>
<td>P1</td>
<td>P46</td>
<td>Anne</td>
</tr>
<tr>
<td></td>
<td>P2</td>
<td></td>
<td>Mary</td>
</tr>
<tr>
<td></td>
<td>P3</td>
<td>Lisa</td>
<td>Mark</td>
</tr>
<tr>
<td></td>
<td>Lisa</td>
<td>...</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anne</td>
<td>P46</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mary</td>
<td>Lisa</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Anne</td>
<td>Mark</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mary</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mark</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Participants’ demographic information can be found on Table 4.6. The results aiming to answer RQ-1 are presented in the following section.
5.1. CHANGES IN PSTS’ UNDERSTANDING OF CONTEMPORARY SOCIAL ASPECTS OF NOS

This section answers RQ-1 - “how is PSTs’ understanding of contemporary social aspects of NOS influenced by the research intervention?”. To answer the research question, this section outlines the changes in PSTs’ understanding of EOS and entrepreneurship, i.e. the contemporary social aspects of NOS. The research question draws on the data from both the continuous and once-off PSTE participants, which are presented below.

5.1.1. Changes in the PSTs’ Understanding During the Continuous PSTE

This section presents the changes in PSTs’ understanding of the contemporary social aspects of NOS during the continuous PSTE. To identify these changes, the results of the thematic analysis and network analysis are presented.

5.1.1.1. Thematic Analysis of the Contemporary Social Aspects of NOS

This section presents the themes emerging from the pre and post-interviews relating to PSTs’ understanding of the contemporary social aspects of NOS. Four main themes emerged from the data; “understanding of EOS”, “understanding of entrepreneurship”, “understanding of scientists’ work”, and “fragmentation & hierarchy regarding the subject matter”.

5.1.1.1.1. Understanding of Economics of Science (EOS)

Participants had a limited understanding of the relationship between science and EOS in the pre-interviews. This is evident in the basic relationships that participants made between different concepts (e.g. EOS and science), and the formal EOS language/terminology that they used (e.g. money, finance). In the pre-interviews,
“funding” \((f = 19)\) and “money” \((f = 18)\) were most frequently used words followed by “demand” \((f = 11)\). This also shows that in the pre-interviews, the relationship between science and EOS was mainly viewed in terms of “money”, and participants were only giving a reference to the “funding” aspect of EOS. For example, in the pre-interview, Lisa stated that:

\[
\text{you (as a scientist) could do a lot more if you have funding behind you. The discovery has been made probably due to the fact that they have money to support them.}
\]

(Lisa, the pre-interview in the continuous PSTE)

Furthermore, in the pre-interviews, participants often perceived EOS as having a negative impact on science. That is, they were of the opinion that EOS can limit the type of science that gets conducted. They felt that EOS can dictate what types of research gets done and what does not. Within this context, for example, Anne felt that:

\[
\text{It (economics) limits some areas of science but makes other areas stronger. It limits research in the areas that aren't going to provide a lot of money or aren't going to provide a lot of funding.}
\]

(Anne, the pre-interview in the continuous PSTE)

However, in the post-interviews, participants began to show a broader understanding of EOS. Participants were making more complicated relationships between different concepts (e.g. academia-industry-market relationship) and using the formal EOS language/terminology. Regarding the complex relationships, for example, Mary referred to the academia-industry-market relationship, when she stated in the post-interview that “academia provides the workforce for the industry. The industry just makes the products and sell to the market”. Concerning the formal EOS language/terminology, in the post-interviews, “money” \((f = 28)\), “funding/grant/sponsorship” \((f = 30)\) and “patent” \((f = 33)\) were the most frequently used words. Here, it draws attention that the frequency of patent increased considerably. The patent was referred in the context of commodification and commercialisation of science. “Copyright” \((f = 3)\), “profit” \((f = 3)\), “recognition” \((f = 3)\),

\[23\] \(f = \text{frequency}\)
...“referencing” \( f = 4 \), “supply” \( f = 5 \) and “resources” \( f = 9 \), were also mentioned for the first time in the post-interviews.

Moreover, participants identified both the positive and negative impact of economics on science in the post-interview. Participants referred to positive impact as being the contribution of economics on science and the negative impact as the disadvantages of economics on science. For example, while Mary was mentioning that “economics can hinder the scientific research”, Lisa was addressing that “scientific product is going to be bringing money into the country and increasing export which again would be good for the economy”.

5.1.1.1.2. Understanding of Entrepreneurship

Participants had the best understanding of the topic of entrepreneurship in the pre-interviews. However, their understanding did still develop following the intervention. In the pre-interviews, participants provided very short definitions of entrepreneurship and expressed uncertainty regarding their understanding. For example, while Mary stated that “entrepreneurship probably means business” in the pre-interview, she defined it in the post-interview as:

companies come together with the help of an academic institution or scientist and they work together as one union to help producing product or making a product better to sell it to the market and therefore making the economy better.

(Mary, post-interview in the continuous PSTE)

The above quote also shows that following engagement in the current study, participants started to see the relationship between science and entrepreneurship at a higher and more complex level in the post-interviews. Furthermore, participants’ definitions were extended. That means, they provided more detailed definitions, used more entrepreneurship language/terminology and were less likely to express uncertainty regarding their understanding. Another example showing this is that whilst Anne defined entrepreneurship as “that someone makes their own business” in the pre-interview, she defined it in the post interview as:

it can be a person, it can be a group of people who come up with a project or have an idea or something that they want to develop more ... and they can develop a project, or they can get money to develop something.

(Anne, the post-interview in the continuous PSTE)
As seen in these examples, the formal entrepreneurship language/terminology that participants used showed that participants understanding of entrepreneurship in the pre-interviews related solely to “business” (f = 15); however this changed as a result of the intervention. In the post-interviews, participants referred to developing new ideas/products (f = 9), creating something (f = 4), acquiring resources such as funding (f = 4) and realising opportunities (f =3) as well as “business” (f = 24) when they were making statements related to entrepreneurship.

5.1.1.1.3. Understanding of scientists’ work

This theme related to the participants’ understanding of what scientists do and what norms they adopt in their work relating to EOS and entrepreneurship. In the pre-interviews, participants referred to the norms scientists adopt in their work relating to EOS. For example, Anne felt that EOS can dictate what types of research gets done and what does not and stated that “if there is money in a certain area obviously scientists are going to keep research in that”. All participants viewed scientists as working purely in a laboratory working on experiments. For example, in the pre-interview, Mary stated that “the only professional activity that scientists perform really is the experimentation and the research”.

Participants understanding of the nature of scientists’ work broadened following the intervention. In the post-interviews, participants portrayed a broader understanding of scientists’ work. Within this context, ethical dimensions of a scientists’ job (e.g. honesty) and collaborative aspects of their work (e.g. sharing) were mentioned. For example, in the post-interview, Anne stated that:

it's important to always be looking at the ethical issues in science. There is always going to be conflict no matter what but I suppose just stay true to yourself, be honest.

(Anne, the post-interview in the continuous PSTE)

5.1.1.1.4. Fragmentation & hierarchy in terms of subject matter

Participants portrayed a fragmented and hierarchical understanding of science, EOS and entrepreneurship. In the pre-interviews, a fragmented view of science emerged. Entrepreneurship was viewed as separate to what scientists do (subjects/topics), and it was perceived that a person cannot be an entrepreneur and
a scientist at the same time. For example, Mary referred to “business” when she was talking about “entrepreneurship”, and stated that “business person and science person would not integrate into their work, they cannot work together”.

Moreover, a hierarchy emerged in relation to the relationship between scientists and entrepreneurs, with scientists being at the bottom of the hierarchy. It was perceived that entrepreneurs were the ones in charge and the ones with the ideas. It was perceived that scientists merely worked for the entrepreneur. Business people were viewed as the employers and scientists the employees. For example, Mary stated that “business people hire scientists to do something and they (scientists) get funded by them”. There was still some evidence of this in the post-interview. For example, in the post interviews, when Lisa was asked about how science works in society, she stated that:

I start the process with the entrepreneurs. They have the initial idea. Then scientific research comes.

(Lisa, the post-interview in the continuous PSTE)

As seen in this example, Lisa was still viewing science and entrepreneurship separately.

Overall, there were changes in participants’ understanding of EOS, entrepreneurship and scientists’ work, and participants showed hierarchical/fragmented understanding. This is summarised in Table 5.2 by presenting the relevant words/phrases used by the participants.
Table 5.2: Economics of science related words/phrases used by participants

<table>
<thead>
<tr>
<th>Theme</th>
<th>Interview</th>
<th>Relevant Words/Phrases</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Economics of Science</strong></td>
<td>Pre-interview</td>
<td>Mass production, demand, finance, funding, cost, money, patent, company</td>
</tr>
<tr>
<td></td>
<td>Post-interview</td>
<td>Prices, patent, money, grants, resources, copyright, profit, funding, cost, demand, recognition, government science relationship, cost, resources, sponsorship, commercialising science, supply</td>
</tr>
<tr>
<td><strong>Entrepreneurship</strong></td>
<td>Pre-interview</td>
<td>Business, market</td>
</tr>
<tr>
<td></td>
<td>Post-interview</td>
<td>Business, market, developing new ideas/products, creating, resources, realising opportunities</td>
</tr>
<tr>
<td><strong>Scientists’ work</strong></td>
<td>Pre-interview</td>
<td>Doing science to make money, hiding, secrecy, working in labs, conducting experiments and research</td>
</tr>
<tr>
<td></td>
<td>Post-interview</td>
<td>Honesty, sharing, morals, secrecy, helping each other, doing science to make money, willingness to share as long as the results are published, working in a company, attending conferences, publishing papers</td>
</tr>
<tr>
<td><strong>Fragmentation &amp; hierarchy</strong></td>
<td>Pre-interview</td>
<td>Entrepreneurs and scientists are separate entities, they cannot work together, entrepreneurs are in charge</td>
</tr>
<tr>
<td></td>
<td>Post-interview</td>
<td>Entrepreneurial scientists, entrepreneur-science collaboration, entrepreneurs are in charge (they are the source), entrepreneurs have new ideas, scientists have new ideas</td>
</tr>
</tbody>
</table>

As seen in Table 5.2, participants used more economics of science related words/phrases in the post-interviews than pre-interviews. Furthermore, they were mentioning honesty more than secrecy, and they started to realise that scientists can be entrepreneurs as in entrepreneurial scientists (holistic understanding) in the post interviews.

5.1.1.2. Network Analysis of the Contemporary Social Aspects of NOS

This section explores participants’ understanding of the contemporary social aspects of NOS, which are EOS and entrepreneurship. Within this context, the results from the network analysis are addressed to identify the relevance and
importance of EOS and entrepreneurship to the other components of SIS of science, such as professional activities. The centrality, degree connectivity, density and closeness of the contemporary social aspects and the SAMI cycle framework were explored using network analysis (Peters-Burton 2012, 2015; Peters-Burton and Baynard 2013; Peters-Burton et al. 2017). The centrality was mainly determined according to the betweenness of the nodes in the network analysis map. The degree connectivity was determined according to the number of connections/links/ties between the nodes in the network analysis map. The density was determined by running a density measurement test on UCI Net, and the results were compared with the network analysis map. The closeness was determined according to the distance between the nodes, and the degree of closeness was categorised as very close, close, distant and very distant relationships as explained in Section 4.5.2.1. Then, according to the results of the centrality, degree connectivity, density and closeness, importance and relevance of EOS and entrepreneurship to the other components of SIS of science are presented.

Therefore, through the network analysis, the ties/links that participants make between contemporary social aspects of NOS and other components of SIS of science, such as professional activities were investigated. These components of SIS of science and contemporary social aspects of NOS are referred together as the social aspects of NOS, as described in Chapter Three. Each of these social aspects of NOS is called a “node” in the network analysis maps. There were three participants in the continuous PSTE; Anne, Mary and Lisa. With the data collected from these participants, the network analysis was conducted at both group and individual levels.

5.1.1.2.1. Group Understanding Suggested by the Network Analysis

Group network analysis provided the results about the overall understanding of the group (all three participants) during the pre and post-interviews. The results of the group network analysis showed that even though EOS and entrepreneurship were the central ideas (centrality) and had links with all other nodes (degree connectivity) in both the pre- and post-interviews, they showed tighter (closeness) and more central relationships including more connections (density) in the post-interviews. That is, even though participants perceived EOS and entrepreneurship
as relevant to the social aspects of NOS in both interviews, their understanding of
the relevance and importance of EOS and entrepreneurship to the social aspects of
NOS increased following the intervention. The group network analysis map
emerged from the pre-interviews is presented in Figure 5-1.

In the pre-interviews, concerning centrality, EOS and entrepreneurship were
located between the other nodes. Therefore, they were one of the central nodes on
the map. That is, participants were of the opinion that EOS and entrepreneurship
are of importance in the social aspects of NOS. Concerning degree connectivity,
EOS and entrepreneurship had six links (n = 6) with the other nodes. Figure 5-1
was developed to present the group network analysis map emerged from the pre-
interviews in the continuous PSTE.

Concerning the closeness, EOS had very close relationships with social
certification and dissemination (4.6 cm), professional activities (6.6 cm) and
scientific ethos (8 cm) as well as having close relationships with social organisations and interactions (13.2 cm) and entrepreneurship (13.4 cm) in the pre-interviews. This shows that participants were of the opinion that EOS is most relevant to those with very close relationships (i.e. social certification and dissemination, scientific ethos and professional activities) than the others since they had the closest link with EOS. Furthermore, entrepreneurship had very close relationships with social values of science (4.5 cm), social organisations and interactions (5.9 cm) and scientific ethos (7.2 cm) as well as having close relationships with political power structures (13.1 cm) and EOS (13.4 cm) in the pre-interviews. This shows that participants were of the opinion that entrepreneurship is most relevant to those with very close relationships (i.e. social values of science, social organisations and interactions and scientific ethos) than the others since they had the closest link with entrepreneurship. EOS and entrepreneurship were connected but not as connected as the ones with very close relationships.

To make a comparison between the pre and post-interview results, the group network analysis map emerged from the post-interviews is presented in Figure 5-2. In the post-interviews, while the degree connectivity of EOS and entrepreneurship did not show any changes, their centrality showed minimal changes. That is, participants still perceived the importance of the EOS and entrepreneurship in the social aspects of NOS similar to the pre-interviews. However, the density of both EOS and entrepreneurship increased over two times. While the density of EOS (i.e. the ratio of actual connections to possible connections) increased from 8.1250 to 30.50, entrepreneurship increased from 7.1250 to 24.6250. This shows that both entrepreneurship and EOS were more connected to the components of the SIS of science in the post-interviews. The total number of very close and close relationships that EOS had increased from five to six. EOS had very close relationships with scientific ethos (4.3 cm), entrepreneurship (4.7 cm), professional activities (7.9 cm), social certification and dissemination (8.4 cm) and political power structures (8.5 cm) as well as having a close relationship with social values (10.9 cm) in the post interviews.
Furthermore, the total number of very close and close relationships that entrepreneurship had increased from five to seven in the post-interview. Entrepreneurship had very close relationships with political power structures (4.4 cm), EOS (4.7 cm) and scientific ethos (5.3 cm) as well as having close relationships with social values (9.5 cm), professional activities (11.3 cm), social certification and dissemination (12 cm) and social organisations and interactions (12.6 cm) in the post-interviews.

Overall, the increase in the density of EOS and entrepreneurship and the number of very close and close relationships that EOS and entrepreneurship had showed that there was an increase in Anne’s, Mary’s and Lisa’s understanding of the relevance and importance of EOS and entrepreneurship to the components of SIS of science after the research intervention. Additionally, the changes in the closeness between EOS and entrepreneurship showed that participants perceived EOS and entrepreneurship more relevant to each other since the degree of closeness changed from close to very close. To scrutinise the results, Anne, Mary and Lisa’s network
analysis maps were also examined individually in terms of how participants perceive the relevance and importance of EOS and entrepreneurship to the components of SIS of science.

5.1.1.2.2. Anne’s Understanding Suggested by the Network Analysis

In Anne’s pre-interview, concerning centrality, EOS and entrepreneurship did not locate between the other nodes. Therefore, they were not one of the central nodes on the map. That is, Anne was of the opinion that EOS and entrepreneurship are not very important in the social aspects of NOS. Concerning degree connectivity, EOS and entrepreneurship had a direct link with four other nodes (n = 4) in the pre-interview. The density of EOS (i.e. the ratio of actual connections to possible connections) was 3.4286, and the density of entrepreneurship was 2.2857. Anne’s network analysis map of the pre-interview in the continuous PSTE is presented in Figure 5-3.

Concerning the closeness, EOS had a very close relationship with entrepreneurship (7.3 cm) as well as having close relationships with scientific ethos (9 cm), social organisations and interactions (10.2 cm) and social certification and dissemination (11.2 cm) in the pre-interview. This shows that Anne was of the opinion that EOS is most relevant to entrepreneurship due to having a very close relationship. Furthermore, entrepreneurship had very close relationships with social organisations and interactions (6.8 cm) and EOS (7.3 cm) as well as having close relationships with scientific ethos (14 cm) and social certification and dissemination (14 cm) in the pre-interview. This shows that Anne perceived entrepreneurship the most relevant to those with the very close relationship (i.e. social organisations and interactions and EOS) than the others since they had the closest link with entrepreneurship. To make a comparison between the pre and post-interview results, Anne’s network analysis map of the post-interview is presented in Figure 5-4.
Concerning the closeness, EOS had a very close relationship with entrepreneurship (7.3 cm) as well as having close relationships with scientific ethos (9 cm), social organisations and interactions (10.2 cm) and social certification and dissemination (11.2 cm) in the pre-interview. This shows that Anne was of the opinion that EOS
is most relevant to entrepreneurship due to having a very close relationship. Furthermore, entrepreneurship had very close relationships with social organisations and interactions (6.8 cm) and EOS (7.3 cm) as well as having close relationships with scientific ethos (14 cm) and social certification and dissemination (14 cm) in the pre-interview. This shows that Anne perceived entrepreneurship the most relevant to those with the very close relationship (i.e. social organisations and interactions and EOS) than the others since they had the closest link with entrepreneurship. To make a comparison between the pre and post-interview results, Anne’s network analysis map of the post-interview is presented in Figure 5-4.

To compare Anne’s pre and post-interviews and summarise the changes in the centrality, degree connectivity, density and closeness of EOS and entrepreneurship, Table 5.3 was developed. These changes reflect the changes in Anne’s understanding of EOS and entrepreneurship in relation with the social aspects of NOS.
Table 5.3: The centrality, degree connectivity, density and closeness of EOS and entrepreneurship (Anne’s pre and post-interview)

<table>
<thead>
<tr>
<th>The name of the node</th>
<th>Type of measurement</th>
<th>Pre-interview</th>
<th>Post-interview</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Centrality</strong></td>
<td>Not central</td>
<td>Central</td>
<td></td>
</tr>
<tr>
<td><strong>Degree connectivity</strong></td>
<td>4</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td>3.4286</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td><strong>EOS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Very close relationships</strong></td>
<td>Entrepreneurship (7.3 cm)</td>
<td></td>
<td>Social organisations and interactions (4.1 cm)</td>
</tr>
<tr>
<td></td>
<td>EOS (7.3 cm)</td>
<td></td>
<td>Professional activities (6.7 cm)</td>
</tr>
<tr>
<td><strong>Close relationship</strong></td>
<td></td>
<td></td>
<td>Scientific ethos (8 cm)</td>
</tr>
<tr>
<td><strong>Closeness</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scientific ethos (9 cm)</td>
<td></td>
<td>Political power structures (13.1 cm)</td>
</tr>
<tr>
<td></td>
<td>Social organisations and interactions (10.2 cm)</td>
<td></td>
<td>Entrepreneurship (13.3 cm)</td>
</tr>
<tr>
<td></td>
<td>Social certification and dissemination (11.2 cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Entrepreneurship</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Very close relationships</strong></td>
<td>Social organisations and interactions (6.8 cm)</td>
<td>EOS (7.3 cm)</td>
<td>Political power structures (5.9 cm)</td>
</tr>
<tr>
<td></td>
<td>EOS (7.3 cm)</td>
<td></td>
<td>Scientific ethos (7.2 cm)</td>
</tr>
<tr>
<td><strong>Close relationship</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Scientific ethos (14 cm)</td>
<td></td>
<td>Social values (13.1 cm)</td>
</tr>
<tr>
<td></td>
<td>Social certification and dissemination (14 cm)</td>
<td>EOS (13.3 cm)</td>
<td></td>
</tr>
</tbody>
</table>

Table 5.3 shows that Anne’s results of the network analysis measures of EOS and entrepreneurship, which are centrality, degree connectivity, density and closeness.
(the total number of very close and close relationships) have increased after attending the intervention. In the post-interview, both EOS and entrepreneurship became central, and their degree connectivity almost doubled. The density of both EOS and entrepreneurship increased over twice as much.

Furthermore, while EOS and entrepreneurship had very close and close relationships with the components of SIS of science in the pre-interview they had five very close and close relationships in the post-interview. The direct relationships of EOS and entrepreneurship with professional activities and social values newly emerged in the post-interviews. For example, Anne did not refer to the relationship between professional activities and EOS in the pre-interview, but she referred to this relationship in the post-interview by stating that “scientists need money to perform a professional activity like an experiment”. Political power structures was mentioned for the first time in the post-interviews. For example, she mentioned human cloning as an ethical issue and stated that “the government wouldn't let someone be cloned”. In this example, ethical issue (human cloning) refers to the scientific ethos and the government’s impact on it refers to political power structures. The increases in network analysis measures (i.e. centrality, degree connectivity, density and closeness) indicate the changes in Anne’s understanding as perceiving EOS and entrepreneurship more connected and important to the components of the SIS of science in the post-interview.

5.1.1.2.3. Mary’s Understanding Suggested by the Network Analysis

In Mary’s pre-interview, concerning centrality, EOS and entrepreneurship located between the other nodes, and therefore they were one of the central nodes on the map. That is, Mary found EOS and entrepreneurship important to the components of SIS of science in the pre-interviews. Concerning degree connectivity, EOS and entrepreneurship had seven links with the other nodes (n = 7). The density of EOS (i.e. the ratio of actual connections to possible connections) was 3.2500, and the density of entrepreneurship was 3.1250. Mary’s network analysis map of the pre-interview in the continuous PSTE is presented in Figure 5-5.
Figure 5-5: Mary’s network analysis map in the continuous PSTE (pre-interview)

Figure 5-6: Mary’s network analysis map in the continuous PSTE (post-interview)
Concerning the closeness, EOS had very close relationships with social certification and dissemination (4.7 cm), professional activities (6.6 cm) and scientific ethos (8 cm) as well as having close relationships with social organisations and interactions (13.2 cm) and entrepreneurship (13.4 cm) in the pre-interview. This shows that Mary was of the opinion that EOS is most relevant to those with very close relationships (i.e. social certification and dissemination, professional activities and scientific ethos). Furthermore, entrepreneurship had very close relationships with social values (4.5 cm), social organisations and interactions (5.9 cm) and scientific ethos (7.2 cm) as well as having close relationships with political power structures (13.1 cm) and EOS (13.4 cm) in the pre-interview. This shows that Anne perceived entrepreneurship the most relevant to those with the very close relationships than the others since they had the closest links with entrepreneurship. To make a comparison between the pre and post-interview results, Mary’s network analysis map of the post-interview is presented in Figure 5-6.

To compare Mary’s pre and post-interviews and summarise the changes in the centrality, degree connectivity, density and closeness of EOS and entrepreneurship, Table 5.4 was developed. These changes reflect the changes in Mary’s understanding of EOS and entrepreneurship in relation with the social aspects of NOS. Table 5.4 shows that the centrality of EOS decreased and degree connectivity stayed the same in the post-interview, while the density and closeness (the total number of very close and close relationships) of EOS increased. The density of EOS increased almost three times. When Mary had five very close and close relationships in the pre-interview, it increased to six in the post-interview. Furthermore, the centrality, degree connectivity and closeness of entrepreneurship stayed almost the same while the density of entrepreneurship was increasing. The density of entrepreneurship increased over twice as much.
Table 5.4: Very close and close relationships of EOS and entrepreneurship with the other nodes (Mary’s pre and post-interview)

<table>
<thead>
<tr>
<th>The name of the node</th>
<th>Type of measurement</th>
<th>Pre-interview</th>
<th>Post-interview</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Centrality</strong></td>
<td>Central</td>
<td>Not central</td>
<td></td>
</tr>
<tr>
<td><strong>Degree connectivity</strong></td>
<td>7</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td>3.2500</td>
<td>12.1250</td>
<td></td>
</tr>
<tr>
<td>EOS</td>
<td><strong>Very close relationships</strong> Social certification and dissemination (4.7 cm) Professional activities (6.6 cm) Scientific ethos (8 cm)</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td><strong>Closeness</strong></td>
<td>Social organisations and interactions (13.2 cm) Entrepreneurship (13.4 cm)</td>
<td>Social certification and dissemination (10.5 cm) Scientific ethos (11.8 cm) Social values (12.6 cm) Entrepreneurship (12.7 cm) Social organisations and interactions (13 cm) Political power structures (14.4 cm)</td>
<td></td>
</tr>
<tr>
<td><strong>Entrepreneurship</strong></td>
<td>Central</td>
<td>Central</td>
<td></td>
</tr>
<tr>
<td><strong>Degree connectivity</strong></td>
<td>7</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td><strong>Density</strong></td>
<td>3.1250</td>
<td>7.7500</td>
<td></td>
</tr>
<tr>
<td><strong>Very close relationships</strong> Social values (4.5 cm) Social organisation and interactions (5.9 cm) Scientific ethos (7.2 cm)</td>
<td>Social values (7.3 cm) Social organisations and interactions (7.4 cm) Professional activities (7.7 cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Closeness</strong></td>
<td>Political power structures (13.1 cm) EOS (13.4 cm)</td>
<td>EOS (12.7 cm) Social certification and dissemination (14.4 cm)</td>
<td></td>
</tr>
</tbody>
</table>
Table 5.4 showed that even though there was no change in the relevance of EOS and entrepreneurship according to the degree connectivity, there were notable changes in the links that she made between the nodes. These changes are evident in Figure 5-5 and Figure 5-6. In this sense, for example, while social values of science, entrepreneurship, social organisations and interactions and political power structures became closer to EOS; others (i.e. social certification and dissemination, professional activities and scientific ethos) became more distant. That is, Mary found social values of science, entrepreneurship, social organisations and interactions and political power structures more relevant to EOS after the intervention. Perhaps these findings are due to the study focusing on the SAMI cycle framework (state/government-academia-market-industry relationship), which was explored within the intervention, and can be the precursor of her understanding of the SAMI cycle framework. Concerning centrality, while EOS was central in the pre-interview, it was not central in the post-interview. Entrepreneurship, however, was central in both interviews. The reason for this change might be that Mary found entrepreneurship easier to teach and understand than EOS. This may be observed when Mary stated that:

… with entrepreneurship you can explain a concept or you can give a physical example, where economics is a bit more difficult for them to understand . . . .

(Mary, post-interview of the continuous PSTE)

The results of degree connectivity, closeness and centrality may show that Mary found EOS relevant to social aspects of NOS since the beginning of the study; however, either she started to view EOS in NOS as less important, or the importance of other aspects also increased following engagement in the study. Furthermore, entrepreneurship was central in both interviews. However, while Mary was of the opinion that entrepreneurship and science are two separate things at the beginning of the pre-interview, her opinion has changed engaging in the study. Once she was asked the reason for her opinion, Mary stated that:

if you put science and business as two things, a science person who is actually doing the work or doing research for science, and an individual person who is doing business would not integrate their work.

(Mary, pre-interview of the continuous PSTE)
Throughout the current study, Mary started to mention that science and entrepreneurship are relevant. When the researcher questioned the reason for this change, Mary stated that:

when you started to pose questions to me I did not see it (entrepreneurship and science relationship). I think it was our first interview and I mentioned some kind of industry and then you asked if I see science there and then I had to think to myself; ‘No, actually I do see science there’ so I started to see the link between the two different aspects.

(Mary, the once-off PSTE interview)

As a result, even though centrality showed a slight decrease, closeness and density in the network analysis results showed an increase. This might mean that while Mary’s understanding of the importance of EOS in the social aspects of NOS decreased slightly, her understanding of the connection of EOS to the social aspects of NOS increased. Similarly, even though centrality, degree connectivity and closeness stayed almost the same in the network analysis results, density showed an increase. This may indicate that while Mary’s understanding of the importance of entrepreneurship in the social aspects of NOS stayed almost the same, her understanding of the connection of entrepreneurship to the social aspects of NOS increased slightly. There might be different reasons for this change, such as finding entrepreneurship easy to teach or having a better understanding of entrepreneurship, since Mary was one of the participants who completed a module on entrepreneurship prior to engaging in the intervention.

5.1.1.2.4. Lisa’s Understanding Suggested by the Network Analysis

In Lisa’s pre-interview, concerning centrality, EOS did not locate between the other nodes (not central) but entrepreneurship located between the other nodes (central). Entrepreneurship was the only central node on the map in the pre-interview. That is, Lisa perceived entrepreneurship important in the social aspects of NOS. Concerning degree connectivity, EOS had a direct link with five other nodes ($n = 5$), and entrepreneurship had a direct link with six other nodes ($n = 6$) in the pre-interview. Lisa’s network analysis map of the pre-interview in the continuous PSTE is presented in Figure 5-7.
Figure 5-7: Lisa’s network analysis map in the continuous PSTE (pre-interview)

Figure 5-8: Lisa’s network analysis map in the continuous PSTE (post-interview)
Concerning the closeness, EOS did not have any very close relationships, but it had close relationships with professional activities (9.3 cm) and social organisations and interactions (10.1 cm) in the pre-interview. This shows that Lisa was of the opinion that even though EOS is not highly relevant to any social aspects of NOS, it is most relevant to professional activities and social organisations and interactions than the others due to the close relationships between them. Furthermore, entrepreneurship had very close relationships with scientific ethos (7 cm) and social values (8 cm) as well as having close relationships with social organisations and interactions (10.2 cm), social certification and dissemination (10.4 cm) and professional activities (10.6 cm) in the pre-interview. This shows that Lisa perceived entrepreneurship as the most relevant to those with the very close relationship (i.e. scientific ethos and social values) than the others since they had the closest link with entrepreneurship. To make a comparison between the pre and post-interview results, Lisa’s network analysis map of the post-interview is presented in Figure 5-8.

To compare Lisa’s pre and post-interviews and summarise the changes in the centrality, degree connectivity, density and closeness of EOS and entrepreneurship, Table 5.5 was developed. These changes reflect the changes in Lisa’s understanding of EOS and entrepreneurship in relation with the social aspects of NOS. Table 5.5 shows that Lisa’s results of the network analysis measures of EOS and entrepreneurship, which are degree connectivity, density and closeness (the total number of very close and close relationships), have increased after attending the intervention. Only the centrality of entrepreneurship did not change much. While entrepreneurship was the only central idea in the pre-interview, both EOS and entrepreneurship were central in the post-interview. In the post-interview, both EOS and entrepreneurship were central, and their degree connectivity increased. The density (i.e. the ratio of actual connections to possible connections) of both EOS and entrepreneurship increased over three times.
Table 5.5: Very close and close relationships of EOS and entrepreneurship with the other nodes (Lisa’s pre and post-interview)

<table>
<thead>
<tr>
<th>The name of the node</th>
<th>Type of measurement</th>
<th>Pre-interview</th>
<th>Post-interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>EOS</td>
<td>Centrality</td>
<td>Not central</td>
<td>Central</td>
</tr>
<tr>
<td></td>
<td>Degree connectivity</td>
<td>5</td>
<td>7</td>
</tr>
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<td></td>
<td>Density</td>
<td>2.4286</td>
<td>8.6250</td>
</tr>
<tr>
<td></td>
<td>Very close relationships</td>
<td>N/A</td>
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<td></td>
<td>Closeness</td>
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<td></td>
<td>Close relationship</td>
<td>Professional activities (9.3 cm)</td>
<td>Scientific ethos (9.2 cm)</td>
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<td></td>
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<td>Social organisations and interactions (10.1 cm)</td>
<td>Political power structures (10 cm)</td>
</tr>
<tr>
<td>EOS</td>
<td>Centrality</td>
<td>Central</td>
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<tr>
<td></td>
<td>Degree connectivity</td>
<td>6</td>
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<tr>
<td></td>
<td>Density</td>
<td>2.5714</td>
<td>8.3750</td>
</tr>
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<td></td>
<td>Very close relationships</td>
<td>Scientific ethos (7 cm)</td>
<td>Social values (2.4 cm)</td>
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<td>Social values (8 cm)</td>
<td>Social organisations and interactions (2.7 cm)</td>
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<td></td>
<td>Closeness</td>
<td>Social organisations and interactions (10.2 cm)</td>
<td>Professional activities (9 cm)</td>
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<td></td>
<td>Close relationship</td>
<td>Social certification and dissemination (10.4 cm)</td>
<td>Scientific ethos (11.6 cm)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Professional activities (10.6 cm)</td>
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</table>

Due to the very close and close relationships Lisa was able to make, it can be said that Lisa perceived EOS and entrepreneurship more relevant to each other and the
components of the SIS of science after the intervention. Furthermore, Lisa’s perception regarding the closeness of EOS and entrepreneurship to the SIS of science increased. The close and very close relationships that EOS has increased from two to six, those relationships that entrepreneurship had increased from five to six.

The direct relationship of EOS with social certification and dissemination newly emerged, and political power structures mentioned for the first time in the post-interview. For example, the relationship between EOS and social certification and dissemination emerged when Lisa stated that “the reason for publishing is to attract companies for recognition and funding”. In this example, recognition and funding referred to EOS while publishing referred to social certification and dissemination. These newly emerging relationships demonstrates the increase in Lisa’s understanding of the connection of EOS and entrepreneurship to the social aspects of NOS during the intervention. The increases in network analysis measures (i.e. centrality, degree connectivity, density and closeness) indicate the changes in Lisa’s understanding as perceiving EOS and entrepreneurship more connected and important to the components of the SIS of science in the post-interviews.

Overall, there were improvements in Anne and Lisa’s understanding of the connection and importance of EOS and entrepreneurship to the SIS of science after the intervention. However, while Mary’s understanding of the importance of EOS in the social aspects of NOS decreased slightly, her understanding of the connection of EOS to the social aspects of NOS increased. Furthermore, Mary’s understanding of the importance of entrepreneurship in the social aspects of NOS stayed almost the same, but her understanding of the connection of entrepreneurship to the social aspects of NOS increased slightly. Some of the possible reasons for this change in Mary’s results were discussed during the section. One reason might be that even though Anne and Lisa have not completed a module(s) on entrepreneurship and/or economics at post-primary level and/or university, Mary has completed.
5.1.2. Changes in the PSTs’ Understanding During the Once-off PSTE

This section presents the changes in PSTs’ understanding of the contemporary social aspects of NOS during the once-off PSTE. To identify these changes, the results of the Wilcoxon signed-rank test and thematic analysis are presented in this section. The changes in the participants’ understanding of EOS are presented in Section 5.1.2.1, and the changes in the participants’ understanding of entrepreneurship are presented in Section 5.1.2.2.

5.1.2.1. Changes in PSTs’ Understanding of Economics of Science (EOS)

To determine PSTs’ understanding of EOS during the once-off PSTE, both qualitative and quantitative data were collected from 50 PSTs. As the quantitative method, pre- and post-questionnaires were applied. 12th, 21st, 23rd and 24th statements in the questionnaires were targeting EOS. As mentioned in Section 4.5.3, a null hypothesis and an alternative hypothesis were developed to answer the RQ-1. These hypotheses are:

Null Hypothesis=

\[ H_{01}: \text{There is no significant difference in the mean rank of PSTs’ understanding of EOS before and after the research intervention.} \]

Alternative Hypothesis=

\[ H_{a1}: \text{There is a significant difference in the mean rank of PSTs’ understanding of EOS before and after the research intervention.} \]

In order to determine which hypothesis to follow, a Wilcoxon signed-rank test was conducted. According to the results, the null hypothesis was rejected, and the alternative hypothesis was accepted because the “p-value” was smaller than .05 (p < 0.05). Therefore, the once-off PSTE elicited a statistically significant change in PST’s views on EOS (Z = -3.391, p = 0.001). Indeed, participants’ median EOS
score increased by 1.00 ($\text{Med}_{\text{pre}} = 13.00$) while the mean increased by 0.82 ($\text{M}_{\text{pre}} = 13.36$). Furthermore, while 28 participants showed an increase in their EOS score, seven participants showed a decrease, and 15 participants showed no difference. That is, there was an increase in the number of participants’ (56%) understanding of EOS while there was a decrease in a minor group of the participants’ understanding (14%). Furthermore, PSTs’ understanding of EOS was also determined according to PSTs’ answers to each EOS-related statement on the questionnaire (12, 21, 23, 24). Overall understanding of these statements increased (See Appendix 25 for further details).

To further examine participants’ ($n = 50$) understanding of EOS, the qualitative data was collected during the “Question Time” parts (first four parts), and Part 7 in the role-play activity, which was collected during the once-off PSTE. In Part 7 of the role-play activity, participants wrote individually their opinion on the role of EOS in how science works in society. Four themes emerged from the data concerning the participants’ understanding of EOS. These themes were “funding”, “science-industry-government relationship”, “economics-market-science relationship”, and “economics-science-technology relationship”.

### 5.1.2.1.1. Funding

Funding was the most frequently mentioned theme. When participants spoke about funding, they referred to the funding of research/experiments and the funding of resources/equipment. For example, P9 stated that “the government provides some funding for research to conduct experiments”. When discussing the issue of funding, many participants mentioned the importance of EOS and the relationship between EOS and funding of science. For example, P31 stated that:

> science depends on resources, funds etc. but the economy has to budget what and how much scientists spend on scientific research

(P31)

Furthermore, many participants were of the opinion that “science would not exist without economics” (P26) due to the important role of “money” in scientific activity. For example:
economics is important in science because without money science would not develop, as research and development needs lots of funding and also money can be made to fund more scientific research by selling current completed scientific projects.

(P2)

the economy has an impact on science as money is a key factor in scientific research, development of new ideas and production of inventions.

(P15)

economics can play an important role. Without money science is very difficult to pursue. You need it to pay for research, ideas to be developed. It influences what we sell, how we sell it, what we buy which in turn influences science. For example, if a material is very dear in a product the scientists can create a new material that could be cheaper.

(P49)

5.1.2.1.2. Science-industry-government relationship

This theme included the relationship between science, industry and government. When participants were talking about this relationship between science, industry and government, they mentioned the development of product/services/goods, the economy-industry relationship and the government’s role within this theme. For example, P35 felt that:

economics helps to provide funding for research by the government and industries. After research/product development, industries sell and receive money from the market.

(P35)

Funding was also relevant here. For example, some participants emphasised that the government and industry provide funding for science. Within this context, P6 stated that:

economics has a big role to play. Without government and funding, many scientific research companies and industries wouldn’t exist. If the economy is in an uncomfortable position, cutbacks in science can often be implemented, which also has a striking impact on the industry.

(P6)
Furthermore, some responses included a reference to sustainability. Some participants addressed the long-term economic and environmental benefits of economics when they were also referring to the relationship between science, industry and government. For example:

science is probably being driven by economics. There should be a space for scientific discovery for the good of humankind that may not be short term economic benefit. This would have to be supported by the government and society.

(Mark, the role-play activity in the once-off PSTE)

the role of economics in science is significant to todays’ society. Issues like global warming, auto emissions, oil reserves, genetics and alternative energies are all factors in todays’ economy and it is important to continue to make breakthroughs.

(P42)

5.1.2.1.3. Economics-market-science relationship

This theme included the relationship between economics, market and science. When participants were talking about this relationship between economics, market and science, they mentioned the needs in the market of the society, the supply and demand, and how the economy dictates the market within this theme. For example, P10 referred to supply and demand and satisfying the needs in the market and that the role of economics is to provide the knowledge to science on supply and demand and to pitch the idea to the market. Likewise, P11 stated that:

economics dictates the market and controls the level of supply and demand for the consumer which in turn affects the scientific industry.

(P11)

P28 addressed that the economy dictates the market when talking about the economics, market and science relationship, and stated that:

the economy can dictate the market. For example, we now face an energy crisis and desperately need energy sources. As such, research in this area is prioritised over some others.

(P28)
Additionally, few participants referred to the relevance of funding to economics when addressing the relationship between economics, market and science. Within this context, P5 stated the relevance of funding to satisfy the need in the market/society:

I understand economics as the funding for what is important/needed in the markets or society. Economics tells the scientists what needs are of the society and in turn scientists get to work at fulfilling those needs.

(P5)

5.1.2.1.4. Economics, science and technology relationship

This theme includes the relationship between economics, science and technology. Regarding this relationship between economic, science and technology, it was suggested that economics can be the driver for technology and provide equipment for research, and therefore, it is linked to technological growth. For example, while P43 was of the opinion that economics is the driver of technology and therefore drives growth, P3 was of the opinion that economics is required to provide the best technology and equipment for research. Additionally, P50 brought up the technology and economic relationship in an example:

economics influences science and how it works in society. E.g. there is a demand for technology products etc. in society and industry, therefore more finance may be given to technology area. Also influences supply and demand of the area of scientists that gets focused on, in terms of a country, government.

(P50)

Overall, the quantitative analysis results showed a significant change in the PSTs’ understanding of EOS in NOS, and qualitative analysis results showed that PSTs found EOS relevant and important in NOS. The emerging themes within the relevance and importance of EOS in NOS were supporting the discussions on the scopes of EOS in this study (See Section 2.2.1).
5.1.2.2. Changes in PSTs’ Understanding of Entrepreneurship in NOS

To determine PSTs’ understanding of entrepreneurship during the once-off PSTE, both qualitative and quantitative data were collected from 50 PSTs. As the quantitative method, pre- and post-questionnaires were applied. 22nd, 26th and 27th statements in the questionnaires were targeting entrepreneurship. As mentioned in Section 4.5.3, a null hypothesis and an alternative hypothesis were developed to answer the RQ-1.

These hypotheses are:

*Null Hypothesis=*  

\[ H_{01}: \text{There is no significant difference in the mean rank of PSTs’ understanding of entrepreneurship before and after the research intervention.} \]

*Alternative Hypothesis=*  

\[ H_{a1}: \text{There is a significant difference in the mean rank of PSTs’ understanding of entrepreneurship before and after the research intervention.} \]

To determine which hypothesis to follow, a Wilcoxon signed-rank test was conducted. As a result of this test, the null hypothesis was rejected, and the alternative hypothesis is accepted since “p-value” was smaller than .05 (p < 0.05). Therefore, the once-off PSTE elicited a statistically significant change in PST’s views on entrepreneurship (Z = -3.146, p = 0.002). While participants’ median entrepreneurship score increased by 1.00 (Med_{pre} = 11.00), mean increased by 0.8 \((M_{pre} = 10.88)\). There was an increase in 26 participants’ entrepreneurship score, while 10 participants’ score decreased and 14 participants’ score stayed the same. That is, there was an increase in the majority of the participants’ (52%) understanding of entrepreneurship, while there was a decrease in close to the quarter of the participants’ understanding (20%). When these participants were examined at individual level, 9 out of 14 participants (64%) were the same participants whose score stayed the same in both EOS and entrepreneurship. It can
be inferred that these participants already had an understanding of EOS and entrepreneurship since their score was over 10 out of 15 in the current study. Furthermore, PSTs’ understanding of entrepreneurship was also determined according to PSTs’ answers to each entrepreneurship-related statement on the questionnaire (22, 26, 27). Overall understanding of these statements increased (See Appendix 25 for further details).

To further examine participants’ (n = 50) understanding of entrepreneurship in NOS, the qualitative data was collected during the “Question Time” parts (first four parts) and Part 7 in the role-play activity which was collected during the second intervention. In Part 7 of the role-play activity, participants wrote individually their opinion on the role of entrepreneurship in how science works in society. Primarily, four themes were emerging from the data on how PSTs perceive the relevance and importance of entrepreneurship to social aspects of NOS:

1. Entrepreneurs come up with new ideas and science facilitates it
2. Someone (including scientists) comes up with ideas and entrepreneurs transfer them
3. Entrepreneurship and science influence each other to reach society
4. Entrepreneurship and science are interwoven

5.1.2.2.1. Entrepreneurs come up with new ideas and science facilitates them

This theme explained how entrepreneurs come up with an idea and scientists develop these ideas. Mainly, it has been mentioned that entrepreneurs create new ideas or products, and scientists conduct research related to these ideas/products and facilitate their development to utilise society.

For example, P23 felt that:

entrepreneurship involves coming up with an idea that will be implied through the help of science, which will improve society in some way shape or form.

(P23)
This theme also referred to job creation (employment), risk-taking skills and professional activities while mentioning that entrepreneurs come up with the ideas, which are developed by science/scientists. Within this context, the job creation feature of entrepreneurship was mentioned by many participants. For example, P3 stated that:

entrepreneurs develop new ideas and concepts to allow science to develop, run tests and investigations to prove the entrepreneurs’ ideas. These entrepreneurs ultimately create jobs for people in science while also coming up with solutions for everyday problems.

(P3)

Some participants addressed that when entrepreneurs are coming up with an idea or creating a product or a business, they utilise risk-taking skills. For example, P19 was of the opinion that entrepreneurship uses scientific knowledge, takes risks and generates business, employment and money. Some participants brought up professional activities, such as conducting research, when they were addressing the relationship between entrepreneurs and scientists. For example, Lisa stated that:

entrepreneurship is necessary to provide the initial idea to the scientist. They (scientists) will then further develop and research the idea. This then links into society as papers maybe released to society about the scientists’ findings.

(Lisa, the once-off PSTE)

A small number of participants highlighted that entrepreneurs come up with ideas or products, and new ideas contribute to the growth of science and scientific knowledge. For instance, P2 mentioned the role of an entrepreneur in the development of science and stated that:

you need an entrepreneur to come up with innovative ideas for science. Without entrepreneurs’ interest and new ideas and discoveries, science may never develop further.

(P2)

5.1.2.2.2. Someone (including scientists) comes up with ideas and entrepreneurs transfer them

This theme explained how someone (including scientists) comes up with discoveries/ideas/products/inventions and entrepreneurs transfer them to the
market or society. Many participants addressed that entrepreneurs provide goods and services to the market. For example, P32 was of the opinion that “entrepreneurship uses scientific knowledge to provide goods and services for consumers/market”.

Numerous participants addressed how the transfer of discoveries/ideas/products/inventions to the market affects society. This impact can involve the advancement of society or satisfying the needs of society. For example, P15 explained that “entrepreneurship works with science to develop ideas/discoveries and gets them out into the market which influences society”. Mary emphasised the role of entrepreneurship in the integration of science into society and stated that:

entrepreneurship gives a means of allowing science integrate into society. For example, an entrepreneur invested and/or made a product such as a phone. This phone is now a part of science, now a part of the society because of the entrepreneur.

(Mary, the role play activity in the once-off PSTE)

Similarly, P10 addressed the importance of entrepreneurship to transfer scientific ideas/discoveries into socially beneficial products:

… without entrepreneurship, scientific discoveries may never make it from an idea into a product or make an improvement in industry. Entrepreneurship provides the initiative needed to benefit society.

(P10)

P5 and P9 were also of the opinion that entrepreneurship transfers discoveries/ideas/products/inventions to the market for social utility and public benefit. Within this context, P5 addressed that:

entrepreneurs bring the inventions, experiments and products to the table from industry and academic institutions. They bring it to the market for society to benefit from it.

(P5)

Some participants also mentioned the role of funding in the transfer of scientific products to the market. For example, P8 was of the opinion that “entrepreneurship
helps scientists to bring their inventions/products/ideas to companies first in order to obtain investment and then to market”.

Several participants felt that entrepreneurs utilise risk-taking skills and create jobs when they transfer scientific products to the market. For example, Mark stated that:

a lot of new ideas come from people who think outside the box. It falls on the entrepreneur to take a risk with these ideas and transfer them to the market. It is only after these ideas/discoveries have been proved successful/working that they are carried forward by the industry to society. They can also create job opportunities.

(Mark, the role play activity in the once-off PSTE)

5.1.2.2.3. Entrepreneurship and science influence each other to reach society

This theme explained how entrepreneurship and science complement and/or drive/influence each other to reach society. The results suggested that the influence of entrepreneurship and science on each other affect the social and economic development of a country and the operation of science through funding. Some participants addressed that entrepreneurship influences science and, science and entrepreneurship relation contributes to the social and economic development of a country. For example, P37 stated that:

entrepreneurship is very important because it influences how science can be incorporated in society by recognising the needs of the people and approaching scientists with business proposals to meet the needs.

(P37)

Few participants mentioned the influence of entrepreneurship and science on each other affect the operation of science through funding. For example, P48 suggested that agencies, the government and entrepreneurs provide money/funding to develop scientific products. Additionally, P27 addressed the possible partnership between entrepreneurs and scientists by stating that “entrepreneurs can take on and partner with scientists”. Even though this is also close to the fourth theme, what P27 referred to entrepreneurs and scientists separately. This result also came up in Section 5.1.1.1 within the context of participants’ fragmented understanding of the
entrepreneurship. However, in the next theme, the features of scientists and
entrepreneurs are combined in one person.

5.1.2.2.4. Entrepreneurship and science are interwoven

This theme explained how entrepreneurship and science are interwoven. Within
this context, this theme referred to entrepreneurial scientists. Some participants
mentioned the social and economic development of a country when they were
referring to the entrepreneurial scientists. For example, P1 was of the opinion that
all scientists are entrepreneurs, and they develop the countries:

without entrepreneurship, no ideas would have been generated in relation to
science. Entrepreneurship isn’t just business related. All scientists are
entrepreneurs because otherwise no idea would came up which lead to an
invention which lead to a product to a theory developing the countries and
making the world better.

(P1)

Likewise, P44 emphasised the necessity to involve entrepreneurial elements in
science for social utility by stating that:

science needs to have an element of entrepreneurship to work in society so
that products, medicine etc. that may be missing or needed can be produced.

(P44)

Many participants mentioned the need for entrepreneurial scientists to make
scientific knowledge and products become available in the market for public use.
For example, Anne stated that:

entrepreneurship is very important in how science works in society. Scientists
need to have entrepreneurship qualities to get products moving in the market
or to make ideas etc. to keep things up to society of science world.

(Anne, the role-play activity in the once-off PSTE)

Likewise, P6 was of the opinion that without entrepreneurship, scientists could not
turn the ideas into products and produce them in a profitable company, and thus
many developments would not happen in science. How entrepreneurship affects
the development of science was also mentioned. Some participants mentioned the
job opportunities when they were referring to the entrepreneurial scientists. For
example, P30 addressed how science and entrepreneurship require each other to start a business and provide job opportunities.

In this section, the quantitative analysis results showed a significant change in the PSTs’ understanding of entrepreneurship in NOS, and qualitative analysis results showed that PSTs found entrepreneurship relevant and important in NOS. Furthermore, the qualitative data provided more information about why PSTs found entrepreneurship significant in science. The emerging themes within the relevance and importance of entrepreneurship in NOS were supporting the discussions conducted on Section 2.3. For example, some attributes of entrepreneurs were mentioned, such as developing new ideas and transferring products to the market. Moreover, some benefits of entrepreneurship came up, such as providing job opportunities. Entrepreneurial scientists was also emphasised both in the themes and Section 2.3.

Overall, both qualitative and quantitative data showed that there were changes in PSTs’ (participants) understanding of EOS and entrepreneurship in NOS during the interventions (the once-off PSTE and the continuous PSTE), which is called “contemporary social aspects of NOS” in the current study. At the end of the interventions, participants found EOS and entrepreneurship more relevant and important to the components of the SIS of science. The majority of participants were of the opinion that EOS and entrepreneurship have an important role in how science works in society. Participants’ opinion of the inclusion of these contemporary aspects of NOS in the curriculum in Ireland was also explored, and the results are presented in the next section.

5.2. PSTS’ PERSPECTIVES ON THE INCLUSION OF THE CONTEMPORARY SOCIAL ASPECTS OF NOS INTO THE JCSS

This section aims to answer RQ-1.1 - what are the perspectives of PSTs on the inclusion of the contemporary social aspects of NOS into the JCSS?. Therefore, this section examines the PSTs’ educational views on the inclusion of EOS and entrepreneurship into the science curriculum in Ireland. The science curriculum of
the junior cycle in Ireland is called the Junior Cycle Science Specification (JCSS). Within the aim of the section, PSTs’ perspectives on the inclusion of EOS into the JCSS are firstly outlined followed by their perspectives on the inclusion of entrepreneurship into the JCSS.

5.2.1. PSTs’ Educational Views on the Inclusion of EOS into the JCSS

This section presents the results relating to the inclusion of EOS into the JCSS from the continuous PSTE and the once-off PSTE respectively. In the continuous PSTE, during the post-interviews participants were asked about the inclusion of EOS in the JCSS. Differing views emerged from the post-interview with continuous PSTE. Both Lisa and Anne supported the inclusion of EOS into the JCSS. They felt that addition of such topics would motivate students and would exemplify the economic forces behind science. For example:

students should learn the process that science goes through and the actual cost of science in society and produce a product and sell it; the impact behind it (science) … .

(Lisa, the post-interview in the continuous PSTE)

However, Anne only supported such inclusion on the condition that it would not overload the science curriculum and would not take time away from exam related issues:

it should be included, but it should not overload the curriculum; just a small bit to discuss how inventions and discoveries could make them (students) money or how a project is influenced by economics. They’d get motivated.

(Anne, the post-interview in the continuous PSTE)

Mary, however, was not in favour of this inclusion. Mary stated that “I can use a small bit of it (economics) to give the examples or tell stories of some things”. Mary’s main concerns, similar to Anne’s, related to overloading the curriculum and having limited teaching hours of science at schools. Other concerns raised by Mary related to the difficulty of teaching EOS and providing relevant and understandable examples for students (e.g. “it is hard to give examples” and “it is difficult for students to understand”). Mary questioned the feasibility of implementing
curriculum change as a reason for not including such topics, as well as the broadness of the topic of economics – which makes it difficult to implement into the science curriculum:

it is hard to change the curriculum at the moment. People are so against trying to change it. I also have seen the debates and the politics about it. It is too much.

(Mary, the post-interview in the continuous PSTE)

In the once-off PSTE, in the questionnaire, PSTs’ were asked their opinions on whether EOS should be integrated into the JCSS. While 42 participants (84%) were supporting this inclusion, 8 participants (16%) were not in favour of this. As a result of the thematic analysis of participants’ justification of their answer, three main themes regarding the benefits of including these topics in JCSS emerged. These included; the benefits of (1) improving understanding of science and economics, (2) improving knowledge of economics in science and (3) improving economics as a skill in science (See Appendix 23 for details of the EOS categorisation in the once-off PSTE).

5.2.1.1. The benefits of improving understanding of science and economics

Participants highlighted the benefits of improving students’ understanding of the relationship between economics and science. These benefits, according to participants, are:

1. increasing their awareness of the socio-economic issues
2. increasing awareness on the social and economic development of a country
3. understanding the cross-curricular links
4. making science more relatable to life
5. realising everyday applications of science

Some participants mentioned increasing the awareness of the socio-economic issues as one of the benefits of improving the understanding of the relationship between economics and science. For example, while P6 believed that this inclusion helps to “understand the economic climate of their world”, P15 stated that this
inclusion helps to “educate students about how economics has an effect on them and everything around them”. Many participants mentioned the social and economic development of a country. For example, P11 stated that:

science, economics and the world are connected so why not make students aware of connections and open doors to different areas of work, learn where products come from, benefit society greatly and give the students a different view of science.

(P11)

Many other participants referred to the cross-curricular links, such as Mary. Cross-curricular links refers to the interdisciplinary relationships between different concepts or subjects, such as science and economics relationship. Within this context, Mary stated that:

students should learn how science contributes to society. Students should be able to see the cross-curricular links and see the bigger picture of science, not observing it as a subject through one lens, show science interlinks with other subjects.

(Mary, the post-interview in the once-off PSTE)

Many participants felt that including topics relating to the social aspects of NOS would make science more relatable to life, make students see “the importance of science in our lives” (P43), and hence improve students’ understanding of the topic. For example, P41 addressed that:

this inclusion might allow students to see the point of studying science a bit better and will make students see it as more relatable to their lives.

(P41)

Making students realise the everyday applications of science was highlighted as a benefit of such inclusion. For example, P31 was of the opinion that this inclusion can “give them an understanding of the part that science plays in society with respect to the economy”. Within this context, some (e.g. P17, P30) were of the opinion that economics can help students to understand the scientific world better and would increase students’ interest in science. For example, P8 was of the opinion that:

students have very little experience and understanding about economics generally so for them to understand the world we live in better economics should be incorporated in some way into the curriculum.

(P8)
Furthermore, improving the understanding of the relationship between economics and science would increase students’ understanding of how the use of economics in science drive the technological advancements. For example, P43 addressed the importance of economics in science as a driver of technology by stating that:

*economics should be involved because students should see the importance of economics in science as a driver of technology. It (this inclusion) can also improve understanding of the importance of science in our lives.*

(P43)

The relationship between economics, science and technology also emerged in Section 5.1.2.

5.2.1.2. The benefits of improving knowledge of economics in science

This theme included the benefits of improving students’ knowledge of the relationship between economics and science. Improving students’ knowledge on this can be useful for students to comprehend “supply and demand” between different concepts, such as economics and science, and the “interdisciplinary nature of science”. A number of participants were of the opinion that the relationship between economics and science is taught in business studies in the transition year but P3 was of the opinion that there is a need, in the science curriculum, to teach the relationship between economics and science for students to comprehend “supply and demand” better. P3 stated that:

*economics in science should be included in the JCSS. It is dealt with in business studies however not enough as in there should be more about supply and demand and various competitive markets.*

(P3)

Furthermore, participants felt that the inclusion of the knowledge of the relationship between economics and science into the JCSS would benefit students’ future career and job opportunities. For example:

*students should have a fundamental knowledge on economics which will benefit them when entering into the working world, which is vital in pitching products for the future.*

(P10)
Similarly, P28 was of the opinion that “inclusion of economics knowledge would be beneficial in adult life and be less intimidating if it were introduced earlier”. Some participants also mentioned how this inclusion of this knowledge can benefit students’ job opportunities in their future life. For example, P11 addressed that gaining this knowledge related to the interdisciplinary nature of science increases job opportunities by “opening doors to different areas of work”. Additionally, P23 was of the opinion that economics knowledge should be included “so students learn how to implement their ideas”.

5.2.1.3. The benefits of improving economics as a skill in science

Many participants were of the opinion that the inclusion of EOS can benefit students by improving their money management skill which is important to be successful in life. For example, P37 stated that “we live in a society influenced by money; therefore we should have the skill to manage it”. Furthermore, the importance of this skill in understanding political power structures was stressed by participants. Political power structures was explained in Chapter One as the relationships between science and race, science and gender, and the politics of government/state and science (Erduran and Dagher 2014a). Furthermore, the relationship between the economics, government and science was also mentioned in Section 5.1.2.2. Here, it was felt that economics, government and science are relevant and therefore improving economics related skills can facilitate improving the understanding of this relationship. For example, P9 stated that:

> it (economics) is a new skill and would benefit them (Junior Cycle students) in the long run to understand more about politics, government etc.

(P9)

Participants felt that engaging with such topics would improve students’ ability to apply their scientific knowledge in other contexts and, as stated above, would result in science becoming more relevant to their lives. P18, for example, felt that economics and developing related skills would increase “their ability to use their knowledge outside of school and develop whatever they like”.

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5.2.1.4. Concerns regarding the inclusion of EOS in the JCSS

As mentioned at the beginning of this section, eight PSTs were not in favour of this inclusion because economics is already covered by business studies and therefore it is not necessary to include it in science. Even though participants were asked about the inclusion of EOS in the science curriculum, some participants felt that topics relating to economics should only be explored within business subjects. Perhaps, this is reflective of the fragmented thinking outlined above in Section 5.1.1.1. For example, P35 stated that “economics should not be covered in the JCSS because it is already covered in junior cycle business and this is enough”.

The main reasons for not supporting this inclusion were explained with not being relevant to each other, being complicated to understand, being difficult for JC level, students being too young to learn this, and not having enough content in science specification. For example, P12 felt that students are too young to learn about economics and stated that:

\[
\text{economics is a very complicated topic and could easily make students confused, so I think it is best to wait until they are a little older to incorporate it into their schooling.}
\]

(P12)

As opposed to considering Junior Cycle students as very young to learn about economics, some participants were of the idea that learning economics at younger ages can benefit students in their future life. For example, P28 was of the opinion that “economy is beneficial in adult life and it would be less intimidating if it was introduced at earlier ages”. Additionally, some other students were of the opinion that while economics is included in business studies, business studies is an optional subject so not all students would engage in such topics. So even though these participants were aware that economics is already included in business studies, they were still supporting its inclusion in science. For example, P27 stated that:

\[
\text{this would be easier for the junior cert students if based mainly in business, but again this should be taught to science students.}
\]

(P27)
Therefore, the majority of the participants were supportive of the inclusion of EOS in the JCSS. The next section presents the PSTs’ opinion on the inclusion of entrepreneurship in the JCSS.

5.2.2. PSTs’ Educational Views on the Inclusion of Entrepreneurship into the JCSS

This section presents the views of continuous PSTE and the once-off PSTE relating to the inclusion of entrepreneurship into the JCSS. Different views emerged in relation to participants views on the inclusion of entrepreneurship in JCSS.

In the continuous PSTE, during the pre-interviews, while Anne and Lisa supported the inclusion of entrepreneurship in science education, Mary was not supportive due to not seeing any relationship between entrepreneurship and science at the beginning of this study. During the first interviews, Anne and Lisa expressed the benefits of this inclusion in (1) making science more interesting, exciting and easier to learn, (2) motivating students, (3) making students think and appreciate where things come from (4) making students realise the benefits of science, and (5) making students comprehend science in a different way than what they see in the textbooks. However, some concerns were also raised about this inclusion. The main concerns were about overloading the curriculum, sacrificing different subjects to include entrepreneurship in science, having limited teaching hours of science at schools, affecting exam preparation within an assessment-driven system, and the broad scope of entrepreneurship, which would make it difficult to teach. For example, participants felt that teachers have limited time for science teaching and exam preparation, and therefore they might not have enough time to teach a new concept. Mary mentioned even if it is for 5 to 10 minutes in each class, teachers may prefer spending this time for teaching exam topics and stated that:

… in each class about 5 to 10 minutes add up during the year, and you need to get the course done for the student.

(Mary, the pre-interview in the continuous PSTE)

Lisa also emphasised a similar concern by stating that “exams also put pressure on students and teachers”. In the post interviews, Mary changed her opinion and even
started to support the inclusion of entrepreneurship in science classes. Benefits of this inclusion were identified by the participants as (1) making science more interesting and exciting and therefore making students more motivated to and engaged with science, (2) contributing to the development of science for the future advancements, (3) helping to learn abstract and difficult aspects of science, (4) providing everyday examples of entrepreneurship behind science, (5) learning how science and scientists work, and (6) supporting imagination and creativity as well as pure scientific knowledge. For example, Lisa was of the opinion that this inclusion can make students learn the operation of science, improve their creativity and contribute to the development of science for the future advancements, and she stated that the inclusion of entrepreneurship in science can:

make the students more aware of the process that a scientist goes through. … It also gets them to think about how they could take something, think about how it works and think about how they can improve it for the future.

(Lisa, the post-interview in the continuous PSTE)

Anne also felt that the inclusion of entrepreneurship in science can contribute to the development of science for the future advancements and stated that “you could've actually seen where you are going with science”. As an example to the participants who mentioned that inclusion of entrepreneurship in science can help students to learn abstract and challenging aspects of science and provide students everyday examples of entrepreneurship behind science, Mary stated that:

it should be more of an influence on giving examples, everyday examples to help students to learn difficult concepts. I'd use it in a certain concept in science and then see how it is used in industry.

(Mary, the post-interview in the continuous PSTE)

It is suggested that it would be important to improve teachers’ content knowledge on entrepreneurship if they were to teach this topic in a classroom. Within this context, Mary felt that:

it (making the link between science and entrepreneurship) is up to the student to see like the gaps in the market to receive the entrepreneurship of each topic. It is up to the teachers’ business knowledge as well to link this concept to business or product.

(Mary, the post-interview in the continuous PSTE)
Overall, all participants supported the inclusion of entrepreneurship and were of the opinion that including a small bit of entrepreneurship into science by not overwhelming the curriculum can have a positive impact on students’ learning. For instance, Mary exemplified the positive impact of entrepreneurship on learning science from her experience:

… when I was doing the leaving cert, I found one topic in chemistry difficult because it’s so abstract. Now, I can see the everyday application of it, but I didn't get that in leaving cert, so I think it's better if they did get that kind of entrepreneurship included.

(Mary, the post-interview in the continuous PSTE)

In the once-off PSTE, in the questionnaire, PSTs’ were asked their opinions on whether entrepreneurship should be integrated into the JCSS. While 47 participants (94%) were supporting this inclusion, 3 participants (6%) were not in favour of this. As a result of the thematic analysis of participants’ justification of their answer, four main themes emerged; the benefits of (1) improving understanding of the relationship between science and entrepreneurship, (2) improving entrepreneurial skills in science, (3) improving students’ attitudes towards science, and (4) future career.

5.2.2.1. The benefits of improving understanding of the relationship between science and entrepreneurship

The benefits of improving the understanding of the relationship between entrepreneurship and science were addressed predominantly in this theme. These benefits included:

1. providing equal opportunities to everyone
2. developing new ways in which science can be helpful to society
3. understanding the role of science in everyday life
4. increasing interest in science

Every student might not be successful in science; however, they might be successful in other fields. It was believed that teaching entrepreneurship in science classes might give an opportunity to these students, who are unsuccessful in
learning the scientific content, to be successful in the application of science in everyday life. Some participants mentioned how increasing the understanding of the relationship between science and entrepreneurship can provide equal opportunities to everyone. For example, P8 stated that entrepreneurship in science “gives students, who are not as academically capable as others, a chance to succeed”. Moreover, regarding the understanding of the role of science in everyday life, many participants were of the opinion that having knowledge of entrepreneurship can make students realise science in daily life. Within this context, P42 was of the idea that:

students that have an interest in science may not always see its opportunities for entrepreneurship. Entrepreneurship helps students to understand how you use science in everyday life.

(P42)

Likewise, according to Anne:

by the inclusion of entrepreneurship, students might value what they are learning more and see the use of science around. It may encourage them to keep science subjects and take science courses. It helps students to understand why we are part of science better.

(Anne, the once-off PSTE)

In the quote above, while Anne was mentioning how entrepreneurship can improve the understanding of the role of science in everyday life, she was also emphasising that this inclusion can increase interest in science.

Additionally, if entrepreneurship contributes to developing new ideas, products or scientific methods, it can support the development of the society. Developing new ways in which science contributes to society was mentioned by some other participants, such as P8:

students get some experience through business, but there is room for improvement. Students need to be more aware of the relationship between both science and entrepreneurship, to show students the importance of entrepreneurship to develop new scientific ways to help the society.

(P8)
5.2.2.2. The benefits of improving entrepreneurial skills in science

In this theme, predominantly, the benefits of improving the entrepreneurial skills in science were addressed. Within this context, these benefits included increasing new ideas, creativity, innovative thinking, problem solving, decision making, critical thinking, being initiative, converting/implementing an idea into practice such as turning an idea into a product, being able to incorporate science into other areas, money management, and ability to see the bigger picture. Improving students’ capability of developing new ideas, creativity and innovative thinking is important in education. Perhaps, this may be actualised through the use of entrepreneurship, and this may also support students to take initiatives. Some students were of the opinion that students should be encouraged to take the initiative, be innovative and convert new ideas into products. For example, P10 stated that:

students should be encouraged to take the initiative and be able to convert a new idea into something more. Entrepreneurship means converting an idea into practice, and it is an important practice for the future. Students should be able to convert ideas into useful products.

(P10)

Furthermore, improving entrepreneurial skills in science can benefit students by viewing science from a broader perspective and realising the everyday applications of science. Within this context, Mark felt that:

it should be included because it needs to be taught to students to think outside the box. It helps to improve students’ thinking skills and thinking of practical aspects of their subject by relating it to real life.

(Mark, the once-off PSTE)

Additionally, P29 called entrepreneurship a life skill which needs to be learned.

5.2.2.3. The benefits of improving entrepreneurial attitudes in science

This theme included the benefits of improving students’ entrepreneurial attitudes in science. Improving students’ entrepreneurial attitudes in science may increase students’ enthusiasm, confidence and interest. Furthermore, entrepreneurship can
encourage students to share ideas and convey the interest in science. Some participants felt that the inclusion of entrepreneurship can improve entrepreneurial attitudes in science and benefit students to gain fundamental science knowledge in everyday life. Within this context, P40 was of the opinion that this inclusion encourages students to share their ideas and make students to learn science in daily life:

this inclusion opens students up to sharing their ideas and conveying interest. It also helps to gain a basic background on the fundamental use of science in everyday life.

(P40)

The inclusion of entrepreneurship in science classes can also improve entrepreneurial attitudes in science and therefore enthuse students in science. For example, according to P18, “entrepreneurship should be included in the JCSS because it gives students a drive and enthusiasm in their work”.

5.2.2.4. The benefits for future career

The inclusion of entrepreneurship in the JCSS may also benefit students’ future career by providing independence in the workplace, helping students to start a business of a scientific product, enabling students to create and realise new job opportunities, getting students ready for future jobs. Due to not taking economics and entrepreneurship related classes, students might not have knowledge of the industry. The inclusion of entrepreneurship in science classes can improve students’ knowledge of the industry and prepare them for their future jobs. Many participants mentioned that this inclusion can prepare students for future jobs, such as P11 who stated that:

students at second level do not know a lot about the industry or how a product is produced. This inclusion provides the knowledge for students to know where products come from. It will also create more aware and intuitive students who will be confident in their chosen sector.

(P11)

As seen in the quote above, having knowledge of the industry not only creates industry-ready graduates but also increases students’ confidence by providing content knowledge and skills. Furthermore, this inclusion can increase students’
interest and curiosity in science, and therefore encourage them to make discoveries in their future job. In this sense, P35, for example, stated that:

it can give the students a sense of achievement or even push them into wanting to discover and research products/cures later in life.

(P35)

Additionally, the inclusion of entrepreneurship in science can improve students’ entrepreneurial skills, such as being initiative, and motivation in science, which might result in the success of students in their future career. Some participants mentioned the importance of entrepreneurial and scientific skills for future success. For example, P19 stated that:

the youth of our world needs their own initiative and motivation to be successful, they need to know skills and values. They need to link their scientific and entrepreneurial skills for future success.

(P19)

5.2.2.5. Concerns regarding the inclusion of Entrepreneurship in the JCSS

As mentioned at the beginning of the section, three PSTs were not in favour of this inclusion because of the Junior Cycle students’ age, the content covered by business studies and believing that entrepreneurial skills cannot be taught. Between these three participants, while P37 did not provide any information about the reason, P46 was of the opinion that the Junior Cycle Science already has too much content to be taught and also “you need a mature outlook to be entrepreneurial”, and P47 was of the opinion that “entrepreneurship is more of a trait that someone was born with and cannot be taught within a classroom”. Moreover, some other participants were not in favour of this inclusion because economics is already covered by business studies and therefore it is not necessary to include it in science.

Some other concerns raised by the participants were that teachers have limited teaching hours of science at schools, and the content may not be pedagogically suited for Junior Cycle students and therefore might cause confusion. Although some participants were of the opinion that students are very young to learn about entrepreneurship, some others disagreed that. For example, P2 was of the opinion that:
being able to come up with new ideas is important for society, and it is never too early to be creative. We always need people being innovative and inventing things.

(P2)

Likewise, P6 stated that:

developing entrepreneurship is essential for the success of science in the long run. The earlier it is introduced the greater the success. Entrepreneurship will be a key factor in developing science. It is good to learn at a young age.

(P6)

Therefore, the majority of the participants were supportive of the inclusion of entrepreneurship in the JCSS.

5.3. CONCLUSION

This chapter aimed to answer the research questions relevant to the contemporary social aspects of NOS (RQ-1 and RQ-1.1). The findings presented in this chapter showed that there were improvements in participants’ understanding of the contemporary social aspects of NOS and the majority of participants supported the inclusion of this into the JCSS. Section 5.1 aimed to explore the changes in PSTs’ understanding of the contemporary social aspects of NOS (RQ-1).

The network analysis was conducted through UCI Net and findings showed that although Anne and Lisa’s understanding of the connection and importance of EOS and entrepreneurship in NOS has improved during the continuous PSTE, Mary’s understanding of the importance of EOS in the social aspects of NOS decreased slightly, her understanding of the connection of EOS to the social aspects of NOS increased. Furthermore, Mary’s understanding of the importance of entrepreneurship in the social aspects of NOS stayed almost the same, but her understanding of the connection of entrepreneurship to the social aspects of NOS increased slightly. Thematic analysis showed an increase in all participants’ understanding. The difference in Mary’s results might be because Mary did not find EOS less important but she found the other social aspects of NOS more important. Furthermore, Mary already had a good understanding of
entrepreneurship, since she was one of the participants who completed a module on entrepreneurship.

In the once-off PSTE, two hypotheses\(^{24}\) were developed to answer RQ-1. The Wilcoxon signed-rank test was performed through SPSS and results showed that the once-off PSTE elicited a statistically significant change in PST’s views on EOS (\(Z = -3.391, p = 0.001\)) and entrepreneurship (\(Z = -3.146, p = 0.002\)). Since “p-value” was smaller than \(.05\), the alternative hypothesis was accepted. Likewise, the thematic analysis results showed the participants’ understanding of EOS and entrepreneurship at the end of once-off PSTE. Emerging entrepreneurship-related themes supported the discussions conducted on Section 2.3. For example, some attributes of entrepreneurs were mentioned, such as developing new ideas and transferring products to the market. Moreover, some benefits of entrepreneurship came up, such as providing job opportunities.

Section 5.2 aimed to explore the participants’ views on the inclusion of the contemporary social aspects of NOS into the JCSS (RQ-1.1). Thematic analysis results of the continuous PSTE showed that all participants supported the inclusion of EOS into the JCSS to motivate and engage students in science. Concerning the inclusion of entrepreneurship into the JCSS, while Mary and Lisa were supporting this inclusion during the pre-interviews, all participants were supporting it during the post-interviews. The main reasons for supporting the inclusion of entrepreneurship into the JCSS were to (1) motivate and engage students in science, (2) make students realize science in everyday life, (3) have better understanding of science and how science works, and (4) supporting imagination and creativity as well as pure scientific knowledge. However, some concerns raised relating to the inclusion of both EOS and entrepreneurship, which were overloading the curriculum and having a limited duration of science teaching at schools. The once-off PSTE results showed that even though the majority of the participants were supporting the inclusion of EOS and entrepreneurship into the JCSS, they were more in favour of the inclusion of entrepreneurship (94%) than EOS (84%). There were many reasons for supporting the inclusion of EOS and entrepreneurship, but

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\(^{24}\) Null Hypothesis (\(H_{01}\)) = There is no significant difference in the mean rank of PSTs’ understanding of EOS before and after the research intervention.

Alternative Hypothesis (\(H_{a1}\)) = There is a significant difference in the mean rank of PSTs’ understanding of EOS before and after the research intervention.
the common ones were the benefits of improving students’ understanding, skills and attitudes. Participants who were not in favour of this inclusion were more exam oriented. That is, they were of the opinion that the science classes are exam focused and there is not enough time to explore science in different concepts, such as entrepreneurship. In the next chapter, the results from the participants’ opinion on the SAMI cycle framework and the inclusion of the SAMI cycle framework to the JCSS are presented.
6 CHAPTER SIX: THE SAMI CYCLE FRAMEWORK AND PSTS’ EXPERIENCES OF THE INTERVENTIONS

The SAMI cycle framework, illustrating the relationship between the state/government, academia, market and industry, was introduced and justified in Chapter Three. This section presents the results relating to PSTs’ experiences of the continuous PSTE and once-off PSTE in relation to the SAMI cycle framework. This chapter aims to answer RQ-2 and RQ-2.1. To answer these research questions, the thematic analysis, network analysis and the Wilcoxon signed-rank test were utilised. The same participants, as outlined in Chapter Four and Chapter Five, participated in this aspect of the study. Please see Section 4.4.1 and Chapter Five for a description and outline of these participants.

6.1. PSTS’ UNDERSTANDING OF THE SAMI CYCLE FRAMEWORK

This section answers the RQ-2, which is “How is the PSTs’ understanding of the relationship between state/government, academia, market and industry influenced by the research intervention?”. To answer RQ-2, the data from the continuous PSTE was analysed with the use of thematic analysis and network analysis, and the results are presented in Section 6.1.1. Then, the once-off PSTE was analysed with the use of Wilcoxon signed-rank test and thematic analysis, and their results are presented in Section 6.1.2.

6.1.1. Changes in the PSTs’ Understanding During the Continuous PSTE

This section explores the changes in PSTs’ understanding of the relationship between the state/government, academia, market and industry, which is called “the
SAMI cycle framework”. The continuous PSTE data, which were collected from Anne, Mary and Lisa, were analysed by network analysis and thematic analysis. The results of the thematic analysis are presented in the next sub-section.

6.1.1.1. Thematic Analysis of the SAMI Cycle Framework

This section presents the thematic analysis results of the participants’ understanding of the SAMI cycle framework, which illustrates the state/government-academia-market-industry relationship. While doing so, three main themes emerged from the data; moving from fragmented to a whole view of the SAMI cycle framework, understanding of EOS and understanding of entrepreneurship.

6.1.1.1.1. Moving from a fragmented to a whole view of the SAMI cycle framework

In the pre-interviews, participants portrayed a fragmented view of the relationships between the different components of the SAMI cycle framework. For example, the government was viewed as separate to the other components of the SAMI cycle framework. Mainly, in the pre-interviews, participants did not express an opinion on the relevance of state/government to the other components of the SAMI cycle framework, such as academia. Furthermore, participants were only able to make basic dual relationships between different components (e.g. academia-industry relationship). Moreover, participants were not explicitly using the terminology relevant to the components of the SAMI cycle framework (i.e. they were using “company” or “factory” instead of using the word “industry”). For example, Anne explained how science works in society by the relationship between academia and the industry:

the environment is interconnected (pause). If scientists are doing research on animals and plants, they could go and do research in a university or factory, and different people could be doing different research and working together. Then (pause) different organisations or different universities could be working with each other.

(Anne, the pre-interview in the continuous PSTE)
In Anne’s quote above, the university was referring to academia and factory was referring to the industry.

However, in the post interviews, a holistic view was determined. The SAMI cycle framework was perceived as a whole with its four components. As discussed in Chapter Three, if a component of the SAMI cycle framework is missing, the operation of science in society may not be explained completely. In this sense, participants started to have a holistic view of the SAMI cycle framework when they were explaining how science works in society. For example, in the post-interview, Anne again explained how science works in society but this time by perceiving all the components and their relationships included in the SAMI cycle framework:

academia is learning, learning influences industry, and the government are influential on academics because the government can influence what is run by the curriculum ... so the government do influence the schools, colleges and universities where the learning process is taking place. ... This can influence industry and what is processed and what happens and then whatever comes out (products), the industry can come to market and then the government can influence the market because they can decide what's going to be put on the market and what's not going to be put on the market. ... Then, I suppose the academics can be influenced by this because like knowledge can come from the market, from the buyers, from the sellers, from the consumers and all be placed back into the industry, back into the government, back into....

(Anne, the post-interview in the continuous PSTE)

The example above also shows that in the post-interview, Anne could identify more and more complex relationships between different components of the SAMI cycle framework (e.g. academia-market-industry-government relationship) and the terminology used was relevant to the components of the SAMI cycle framework (e.g. direct use of industry and academia). Additionally, participants mentioned the role of the state/government for the first time in the post-interviews while they were explaining how science works in society, which is also evident in the above example.

Participants were more clear about the relationship between state/government, academia, market and industry in the post-interview. For example, Mary felt that she became more aware of the SAMI cycle framework relationships, which was also evident in her network analysis results (See Section 6.1.1.2).
Mary stated that:

when you first asked me this, I couldn’t say many things. If you asked anybody this question I think they find it very hard to see the relationship between them but once you break it down like we did in the activities, I think people can see it. I can see it.

(Mary, the post-interview in the continuous PSTE)

The improvement in participants’ understanding of the relationships included in the SAMI cycle framework can be seen in Table 6.1 more clearly.

Table 6.1: Synopsis of the SAMI cycle framework relationships mentioned in the continuous PSTE

<table>
<thead>
<tr>
<th>Participant</th>
<th>Relationships mentioned in the pre-interview</th>
<th>Relationships mentioned in the post-interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anne</td>
<td>• Academia-market relationship • Academia-factory (industry) relationship</td>
<td>• Government-market relationship • Academia-government relationship • Academia-industry relationship • Industry-market relationship • Academia-market relationship • Government-academia-market-industry relationship</td>
</tr>
<tr>
<td>Mary</td>
<td>• Academia-market relationship • Academia-government relationship • Academia-company (industry) relationship • Government-industry relationship</td>
<td>• Academia-industry relationship • Academia-industry and market relationship • Industry-market relationship • Government-market relationship • Government-industry relationship • Government-academia relationship • Academia-market relationship • Government-academia-market-industry relationship</td>
</tr>
<tr>
<td>Lisa</td>
<td>• Academia-market relationship • Academia-company (industry) relationship</td>
<td>• Academia-government relationship • Academia-market relationship • Academia-market and industry relationship • Academia-industry relationship • Government-academia-market-industry relationship</td>
</tr>
</tbody>
</table>

Table 6.1 demonstrates all the relationships mentioned by the participants during the pre- and post-interviews in the continuous PSTE.

Overall, in the pre-interviews, all participants were able to identify dual relationships between academia and market or academia and industry at a very basic level. Only Mary referred to the academia - government relationship. In the
post interviews, Anne, Mary and Lisa referred to academia-government, academia-market, academia-industry, and academia-market and industry relationships. Anne also expressed the government-market, and industry-market relationships and added that “they can all be related to each other” in the post-interviews. Therefore, how participants view the relationship between the components of the SAMI cycle framework was more holistic in the post-interviews while it was more fragmented in the pre-interviews.

6.1.1.1.2. Economics of Science (EOS)

While participants had a minimal understanding of the role of EOS in the SAMI cycle framework in the pre-interviews, they had a much better understanding of this relationship in the post interviews. This is evident in the participants’ reference to the aspects of EOS in the context of the SAMI cycle framework and awareness of the link of EOS with other components of the SAMI cycle framework.

In the pre-interviews, participants were focusing on the science and industry relations and the role of funding in science. Within this context, Anne, for example, was explaining how a product is produced based on knowledge and research, grouping the products together when she constructed a diagram explaining how science works in society. Mary also referred to the science and industry relationship by referring to the production and stated that:

> science affects the farms, food-wise, because there is like a mass production happening and they are just producing as much food as possible. We see that because society demands it.

(Mary, the pre-interview in the continuous PSTE)

Mary could see the science and industry relationship in the context of the SAMI cycle framework while she was explaining how science works in society.

Funding is also perceived as part of EOS. In this sense, the role and relevance of funding in the operation of science were mentioned. For example, Lisa felt that:

> the cost of funding the research is huge. I think the reason why they would do the publishing article and things could be to attract bigger companies, pharmaceutical companies. Then, these big companies try to invest in their (scientists’) research and fund them to complete the results.

(Lisa, the pre-interview in the continuous PSTE)
In the post-interviews, participants had a broader understanding of the role of EOS in the SAMI cycle framework in the post-interviews. This is evident in their references to all three aspects of EOS, which are *science and scientists in industry*, *funding of research at academic institutions* and *commodification and commercialisation of science*.

Concerning *science and scientists in industry*, PSTs were of the idea that there is a relationship between science and industry. Regarding *funding of research at academic institutions*, participants suggested the importance of the funding in science. Some participants referred to both the academia-industry relationship and the importance of the funding. For example, Mary explained what academia and industry provide to each other and the role of funding in this relationship by stating that:

academia provides the workforce to industry, aids the industry and develops their product further. This is a two-way relationship. The industry is kind of giving back to the academic institutions by sponsoring (providing money, funding) them to conduct their research.

(Mary, the post-interview in the continuous PSTE)

The notable difference between the pre and post-interviews was that PSTs started to refer to *commodification and commercialisation of science* when they were explaining how science works in society. The role of commodifying and commercialising science in the relationship between science and society became clearer. Commodification and commercialisation of science are required to transfer the scientific knowledge and products from scientific field to the market. This process was referred to by Lisa when she was explaining how science works in society:

when they (entrepreneurs) have their scientific product created, they may need to consult with other people and link in with the market. … Then it (scientific product) will go down to industry to produce the product on a larger scale. ... When they have the product ready to sell they’ll try to encourage companies or people to purchase the product.

(Lisa, the post-interview in the continuous PSTE)
6.1.1.1.3. Entrepreneurship

While participants had a very limited understanding of the role of entrepreneurship in the SAMI cycle framework in the pre-interviews, they had a much better understanding of this relationship in the post interviews. This is evident in participants’ use of the entrepreneurship language/terminology in the context of the SAMI cycle framework, and awareness of the link of entrepreneurship with other components of the SAMI cycle framework. While the formal entrepreneurship language/terminology that participants used included mainly “business” in the pre-interviews, “market”, “business”, “entrepreneur”, “buyers” and “sellers” were referred in the post interviews.

In the pre-interviews, participants were focusing on the business. Even though the relationships of the market with other components of the SAMI cycle framework, such as the government, were not mentioned, the market-academia relationship was mentioned broadly. For example, when the researcher asked Mary how science works in society (the SAMI cycle framework), Mary stated that:

… we have made the aeroplane, we’ve made transport.. They all are connected to science. ... If another person came along and had nothing to do with science they probably see science very little in this picture. They see business or something.

(Mary, the pre-interview in the continuous PSTE)

In the above quote, Mary gave an example that shows the relationship between science and entrepreneurship. In this example, Mary focused on science and business separately. She felt that science person could see the science behind it, and another person could see the business behind it. Furthermore, although the example was showing the relationship between the academia and the market, she did not mention this.

Even though Mary mentioned science and business as separate entities which do not come together at the beginning of the pre-interview, she started to address their relationship during the end of the interview. Perhaps, this is reflective of the fragmented view in contemporary social aspects of science outlined above in Section 5.1.1.1.
In the post-interviews, participants mentioned the role of market, entrepreneur and buyers and sellers when explaining how science works in society. Within this context, for example, Mary stated that:

… entrepreneurs can liaise with them (scientists) and with the help of this society entrepreneurs start to make companies and industries, and they make products which can be patented. From this then I suppose they identify the market and liaise, work with the exchange office. That's connected to the seller and the buyer as well maybe small bit. … An entrepreneur can also be a buyer and seller and that creates the market anyway. Then they are able to target the consumers. From that then it's just integrated into society.

(Mary, the post-interview in the continuous PSTE)

As seen in the above quote, Mary referred to academia-market-industry relationship explicitly that she could not do in the pre-interview.

Furthermore, entrepreneurship has a role in providing scientific product or service to the market. Lisa referred to the role of entrepreneurship as coming up with an idea, making discoveries and transferring product or service to the market while she was explaining the role of market, entrepreneur and buyers and sellers in the operation of science in society. Lisa explained how science works in society by stating that:

the entrepreneurs come up with the idea and then either they can do the inventions, or they can give it to someone else depending on what they wanted. Then they are going to do the research on it, and by doing the research, they may discover a product or service that needs to be introduced. … Then I link down to the government. They do have the discovery so they could go to the government for funding. If it was the entrepreneur doing the research and discover if it was a scientific based product or service they will probably be consulting a group of scientists to explore the product in more detail … .

(Lisa, the post-interview in the continuous PSTE)

As seen in the quote above, Lisa also started to identify the role of government in the operation of science in society.

As seen thus far, participants had better use of entrepreneurship language/terminology in the context of the SAMI cycle framework and were able to link entrepreneurship with the components of the SAMI cycle framework, such as the government. In the next section, the network analysis was conducted to
scrutinise the participants’ understanding of the relevance and importance of the state/government, academia, market and industry to each other within the SAMI cycle framework.

6.1.1.2. Network Analysis of the SAMI Cycle Framework

This section explores participants’ understanding of the SAMI cycle framework, which explains the state/government, academia, market and industry relationship. Within this aim, the results from the network analysis were addressed to identify the relevance and importance of the components of the SAMI cycle framework (i.e. the state/government, academia, market and industry) to each other when explaining how science works in society. The same measurements (the centrality, degree connectivity, density and closeness) were applied in the same way with the contemporary social aspects of NOS analysis (Peters-Burton 2012, 2015; Peters-Burton and Baynard 2013; Peters-Burton et al. 2017). Then, according to the results of the centrality, degree connectivity, density and closeness, importance and relevance of the components of the SAMI cycle framework to each other were presented.

Therefore, through the network analysis, the links that participants make between the components of the SAMI cycle framework, state/government, academia, market and industry, were investigated. Each of these components is called a “node” in the network analysis maps. There were three participants in the continuous PSTE; Anne, Mary and Lisa. With the data collected from these participants, the network analysis was conducted at both group and individual levels.

6.1.1.2.1. Group Understanding Suggested by the Network Analysis

Group network analysis provided the results about the overall understanding of the group (Anne, Mary and Lisa) during the pre and post-interviews. The results of the group network analysis showed that even though academia was central (centrality) in both pre and post-interviews, the number of links between the nodes (degree connectivity) increased from four \( n = 4 \) to six \( n = 6 \) in the post-interviews. These new links emerged between the market and the other nodes (industry and government). That is, even though academia was perceived as important by
participants in both interviews, participants’ understanding of the connection of academia to the other nodes increased. Furthermore, participants’ understanding of the importance and connection of the market to the other nodes increased in their post-interviews. The group network analysis map emerged from the pre-interviews is presented in Figure 6-1.

![Figure 6-1: Group network analysis map of the SAMI cycle framework (pre-interview)](image)

In the pre-interviews, concerning centrality, academia located between the other nodes. Therefore, academia was the only central node on the map. That is, participants were of the opinion that academia is the most important and relevant component in the SAMI cycle framework in the pre-interviews. Concerning degree connectivity, Figure 6-1 shows that academia had three links (n = 3) with the other three components of the SAMI cycle framework (i.e. government, industry and market). Industry and state/government had two links (n = 2), and the market had only one link (n = 1). Overall density of the SAMI cycle framework density (i.e. the ratio of actual connections to possible connections) was 1.25. The density of the state/government was 0.75, academia was 2.00, the market was 1.00 and the industry was 1.25. Academia had higher density, which points to that it was more central in the map, and it had closer relationships in comparison to the other nodes. This is also evident in Figure 6-1. This also shows that participants found academia the most connected and related to the SAMI cycle framework.
Concerning the closeness, all the links emerging in Figure 6-1 were representing close relationships. In pre-interviews, while academia had close relationships with industry (14.5 cm), state/government (14.5 cm) and market (14.7 cm), this relationship between academia and market was the only relationship that market had. Furthermore, while the industry had close relationships with academia (14.5 cm) and state/government (14.8 cm), and state/government had close relationships with academia (14.5 cm) and industry (14.8 cm). The findings of the closeness of academia to the other components of the SAMI cycle framework supported the findings from the degree connectivity which represented academia as the most related component to the SAMI cycle framework. Due to the degree connectivity, closeness, centrality and density, it can be said that in the pre-interviews, participants perceived academia as the most related and important component and the market as the least related and important component to the SAMI cycle framework. To make a comparison between the pre and post-interview results, the group network analysis map emerged from the post-interviews is presented in Figure 6-2.

Figure 6-2: Group network analysis map of the SAMI cycle framework (post-interview)
In the post-interviews, regarding centrality, academia was again the only central node on the map. Even though this shows that academia is perceived as the most important and connected component in the SAMI cycle framework, there were changes in the degree connectivity, density and closeness in participants’ understanding of the SAMI cycle framework. For example, concerning degree connectivity, all components had three links \((n = 3)\) with the other nodes. That is, participants found all components of the SAMI cycle framework equally connected and related. Although academia’s degree connectivity stayed the same, other nodes’ degree connectivity increased. Overall degree connectivity increased from four \((n = 4)\) to six \((n = 6)\). The density of the SAMI cycle framework and its components increased between 2.5 and 5 times. The overall SAMI cycle framework increased from 1.25 to 4.8750. The density of state/government increased from 0.75 to 4, academia increased from 2.00 to 5.50, the market increased from 1.00 to 5.25 and industry increased from 1.25 to 4.75. The biggest change in the density was observed in the market. This shows that participants’ understanding of the importance and connections of the market to the SAMI cycle framework increased more than the other components.

The total number of very close and close relationships that the SAMI cycle framework has decreased from four to three; however, even though there were no very close relationships in the pre-interviews, there was a very close relationship between academia and market \((7.3 \text{ cm})\) in the post interviews. Concerning closeness, academia and market had a very close relationship \((7.3 \text{ cm})\), and academia and industry \((10.6 \text{ cm})\) and industry and market \((15.3 \text{ cm})\) had close relationships. The state/government did not have any very close or close relationships. Moreover, whilst participants perceived academia the most connected and important component of the SAMI cycle framework, they found state/government the least connected and important component. This shows that only the relevance of the market increased in the post-interviews.

Overall, the increase in the degree connectivity, density and the newly emerging very close relationship showed that there was an increase in the Anne’s, Mary’s and Lisa’s understanding of the connection and importance of the state/government, academia, market and industry to the SAMI cycle framework increased after the research intervention. Even though the number of close
relationships (closeness) showed a slight decrease, this may not necessarily mean that PSTs found the components of the SAMI cycle framework less connected and important to each other because other findings, such as density, indicate an increase. There might be different reasons for this change, such as having a better understanding of the other components of the SAMI cycle framework. To scrutinise the results, each participant’s (Anne, Mary and Lisa) network analysis map was examined in terms of how participants perceive the relationship between the state/government, academia, market and industry (components of the SAMI cycle framework).

6.1.1.2.2. Anne’s Understanding Suggested by the Network Analysis

In Anne’s pre-interview, concerning centrality, academia was located between the other nodes. Therefore, academia was the only central node on the map. That is, Anne was of the opinion that academia is the most important and relevant component in the SAMI cycle framework. Anne’s network analysis map of the pre-interview in the continuous PSTE is presented in Figure 6-3.

The degree connectivity of the SAMI cycle framework was two (n = 2) due to occurring two links (i.e. academia-market link and academia-industry link). There was no link between state/government and the other components of the SAMI cycle framework. This is because Anne did not mention any relationship involving the state/government during the pre-interview. The density of the framework (i.e. the ratio of actual connections to possible connections) was 1.00. Concerning the closeness, all the links (n = 2) emerging in Figure 6-3 were representing close relationships. These close relationships were academia and industry relationship (13.5 cm), and academia and market relationship (13.5 cm). Due to the degree connectivity, closeness, centrality and density, it can be said that in the pre-interview, Anne perceived academia as the most connected and important component and the state/government as the least connected and important component to the SAMI cycle framework. To make a comparison between the pre and post-interview results, Anne’s network analysis map of the post-interview is presented in Figure 6-4.
Figure 6-3: Anne's network analysis map of the SAMI cycle framework (pre-interview)

Figure 6-4: Anne's network analysis map of the SAMI cycle framework (post-interview)
In the post-interview, concerning centrality, while academia was central in the pre-interview, there was no central idea in the post-interview. Degree connectivity of the SAMI cycle framework increased three times. While Anne could only make two links (n = 2) between the nodes in the pre-interview, she was able to make six links (n = 6) between the nodes in the post-interview. The density of the SAMI cycle framework doubled. While the density was 1.00 in the pre-interview, it increased to 2.00 in the post-interview. The increase in the density shows that Anne started to view the components of the SAMI cycle framework more connected to each other. Regarding closeness, Anne had two close relationships in the pre-interview, which were academia-market (13.5 cm) and academia-industry (13.5 cm) relationships whilst she had one very close relationship between industry and state/government (9.1 cm) as well as having one close relationship between industry and market in the post-interview.

To compare Anne’s pre and post-interviews and summarise the changes in the centrality, degree connectivity, density and closeness of the SAMI cycle framework, Table 6.2 was developed.

Table 6.2: Degree connectivity, closeness and centrality results of Anne in the continuous PSTE

<table>
<thead>
<tr>
<th>Type of measurement</th>
<th>Pre-interview</th>
<th>Post-interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centrality</td>
<td>Academia</td>
<td>N/A</td>
</tr>
<tr>
<td>Degree connectivity</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Density</td>
<td>1.00</td>
<td>2.00</td>
</tr>
<tr>
<td>The SAMI Cycle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Framework</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closeness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very close</td>
<td>N/A</td>
<td>Industry-state/government (9.1 cm)</td>
</tr>
<tr>
<td>relationships</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Close relationship</td>
<td>Academia-Market (13.5 cm)</td>
<td>Industry-Market (15.8 cm)</td>
</tr>
<tr>
<td></td>
<td>Academia-Industry (13.5 cm)</td>
<td></td>
</tr>
</tbody>
</table>

These changes in Table 6.2 reflect the changes in Anne’s understanding of the relationship between state/government, academia, market and industry within the context of the SAMI cycle framework. Anne’s results of the network analysis
measures, which are centrality, degree connectivity, density and closeness (the total number of very close and close relationships), of the SAMI cycle framework indicate that there were improvements in Anne’s understanding of the SAMI cycle framework.

Academia not being the central component in the post-interview might show that Anne started to feel that other components of the SAMI cycle framework are as important as academia. This is evident in the increase in the degree connectivity and density of the components of the SAMI cycle framework. Each node’s degree connectivity increased as well as the degree connectivity of the SAMI cycle framework. This shows that Anne’s understanding of the connection between the components of the SAMI cycle framework and the importance of each component within the framework increased. Furthermore, she started to make new relationships in the post-interviews, such as the government-market relationship.

Increase in the density points to the increase in the number of connections. It may also be the precursor of the changes in the centrality and closeness. Therefore, it can be said that Anne realised the connection between the components of the SAMI cycle framework better. The total number of very close and close relationships stayed the same. However, even though the industry and state/government had a very close relationship in the post-interview, they did not have any relationship in the pre-interview. This shows the increase in the relevance and importance of the industry and the state/government to each other and the SAMI cycle framework. While the connection of academia to the other components and the SAMI cycle framework increased the least, the connection of state/government to the other components and the SAMI cycle framework increased the most. Furthermore, although the government was alienated in the pre-interview, it became very connected and important to the SAMI cycle framework in the post-interview. This can be interpreted from the increase in the degree connectivity from zero to three as well as having a close relationship in the post-interview. That is, Anne started to realise a very close relationship between the state/government and industry after the intervention. Overall, Anne was able to make numerically more and complex relationships in the post-interview, which shows an increase in Anne’s understanding.
6.1.1.2.3. Mary’s Understanding Suggested by the Network Analysis

In Mary’s pre-interview, concerning centrality, academia was located between the other nodes. Therefore, academia was the only central node on the map. That is, Mary was of the opinion that academia is the most important and relevant component in the SAMI cycle framework. Mary’s network analysis map of the pre-interview in the continuous PSTE is presented in Figure 6-5.

The degree connectivity of the SAMI cycle framework was four \( n = 4 \) due to occurring four links (i.e. academia-market, academia-industry, academia-state/government and state/government-industry links). Concerning the closeness, all the links \( n = 4 \) emerging in Figure 6-5 were representing close relationships. These relationships are presented in detail in Table 6.3. Due to the degree connectivity, closeness, centrality and density, it can be said that in the pre-interview, Mary perceived academia as the most connected and important component and the market as the least connected and important component to the SAMI cycle framework. To make a comparison between the pre and post-interview results, Mary’s network analysis map of the post-interview is presented in Figure 6-6.

In the post-interview, concerning centrality, while academia was central in the pre-interview, there was no central idea in the post-interview. Degree connectivity of the SAMI cycle framework increased by 2. While Mary could only make four links \( n = 4 \) between the nodes in the pre-interview, she was able to make six links \( n = 6 \) between the nodes in the post-interview. The density of the SAMI cycle framework increased 2.5 times. Regarding closeness, Mary had four close relationships in the pre-interview whilst she had one very close relationship between academia and industry (3 cm) and one close relationship between market and state/government (10.6 cm) in the post-interview.
Figure 6-5: Mary's network analysis map of the SAMI cycle framework (pre-interview)

Figure 6-6: Mary's network analysis map of the SAMI cycle framework (post-interview)
To compare Mary’s pre and post-interviews and summarise the changes in the centrality, degree connectivity, density and closeness of the SAMI cycle framework, Table 6.3 was developed.

Table 6.3: Degree connectivity, closeness and centrality results of Mary in the continuous PSTE

<table>
<thead>
<tr>
<th>Type of measurement</th>
<th>Pre-interview</th>
<th>Post-interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centrality</td>
<td>Academia</td>
<td>N/A</td>
</tr>
<tr>
<td>Degree connectivity</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Density</td>
<td>1.00</td>
<td>2.50</td>
</tr>
<tr>
<td>The SAMI Cycle Framework</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Very close relationships</td>
<td>N/A</td>
<td>Academia-Industry (3 cm)</td>
</tr>
<tr>
<td>Close relationship</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Academia-Market (14.7 cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Academia-Industry (14.8 cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Academia-State/government (14.8 cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>State/government-Industry (15.9 cm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>State/government-Market (10.6 cm)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

These changes in Table 6.3 reflect the changes in Mary’s understanding of the relationship between state/government, academia, market and industry within the context of the SAMI cycle framework. Mary’s results of the network analysis measures, which are centrality, degree connectivity, density and closeness (the total number of very close and close relationships), of the SAMI cycle framework indicate that there were changes in Mary’s understanding of the SAMI cycle framework.

As in Anne’s result, academia was not the central component in the post-interview. This might show that Mary started to see the other components of the SAMI cycle framework as important as academia. This is evident in the increase in the degree connectivity and density of the components of the SAMI cycle framework. Each node’s degree connectivity except academia increased as well as the degree.
connectivity of the SAMI cycle framework. Furthermore, Mary started to make new relationships in the post-interviews, such as the industry-market relationship.

Increase in the density results in Mary’s network analysis may indicate that Mary realised the connection between the components of the SAMI cycle framework better. In the post-interview, the changes in academia draw attention. While the closeness of academia to the other components of the SAMI cycle framework is decreasing and it is losing its centrality, the degree connectivity of academia is staying the same. However, this does not necessarily mean that academia is not important and connected to the other components of the SAMI cycle framework, but it might demonstrate the changes in Mary’s understanding of the relationships.

For example, while the industry and academia had a close relationship in the pre-interview they had a very close relationship in the post-interview. Also, industry and academia clustered together in the post-interview, which may show that Mary perceived academia and industry as connected and important to each other more than the other components. Furthermore, the density of academia increased from 1.00 to 2.25. This also refutes that academia is not important and connected to the other components of the SAMI cycle framework. Additionally, state/government and market clustered together in the post-interview even though they had no connection between them in the pre-interview.

While the connection of academia to the other components and the SAMI cycle framework increased the least, the connection of the market to the other components and the SAMI cycle framework increased the most. Overall, Mary was able to make numerically more and complex relationships in the post-interview, which shows an increase in Mary’s understanding.

6.1.1.2.4. Lisa’s Understanding Suggested by the Network Analysis

In Lisa’s pre-interview, concerning centrality, academia was located between the other nodes. Therefore, academia was the only central node on the map. That is, Lisa was of the opinion that academia is the most important and relevant component in the SAMI cycle framework. Lisa’s network analysis map of the pre-interview in the continuous PSTE is presented in Figure 6-7.
Similar to Anne’s results, Lisa’s pre-interview results showed that the degree connectivity of the SAMI cycle framework was two (n = 2) due to occurring two links (i.e. academia-market link and academia-industry link). There was no link between state/government and the other components of the SAMI cycle framework. This is because Lisa did not mention any relationship involving the state/government during the pre-interview. The density of the framework (i.e. the ratio of actual connections to possible connections) was 1.00. Concerning the closeness, all the links (n = 2) emerging in Figure 6-7 were representing close relationships. These close relationships were academia and industry relationship (13.5 cm), and academia and market relationship (13.55 cm). Due to the degree connectivity, closeness, centrality and density, it can be said that in the pre-interviews, Lisa perceived academia as the most connected and important component and the state/government as the least connected and important component to the SAMI cycle framework. To make a comparison between the pre and post-interview results, Lisa’s network analysis map of the post-interview is presented in Figure 6-8.

In the post-interview, concerning centrality, while academia was central in the pre-interview, there was no central idea in the post-interview. Degree connectivity of the SAMI cycle framework increased threefold. While Lisa could only make two links (n = 2) between the nodes in the pre-interview, she was able to make six links (n = 6) between the nodes in the post-interview. The density of the SAMI cycle framework increased by 0.75. While the density was 1.00 in the pre-interview, it increased to 1.75 in the post-interview. Regarding closeness, Lisa had two close relationships in the pre-interview, which were academia-market (13.55 cm) and academia-industry (13.5 cm) relationships whilst she had one very close relationship between academia and industry (8.15 cm) as well as having close relationships between academia and market (10.3 cm) and industry and market (12.2 cm) in the post-interview.
Figure 6-7: Lisa's network analysis map of the SAMI cycle framework (pre-interview)

Figure 6-8: Lisa's network analysis map of the SAMI cycle framework (post-interview)
To compare Lisa’s pre and post-interviews and summarise the changes in the centrality, degree connectivity, density and closeness of the SAMI cycle framework, Table 6.4 was developed.

Table 6.4: Degree connectivity, closeness and centrality results of Lisa in the continuous PSTE

<table>
<thead>
<tr>
<th>Type of measurement</th>
<th>Pre-interview</th>
<th>Post-interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Centrality</td>
<td>Academia</td>
<td>N/A</td>
</tr>
<tr>
<td>Degree connectivity</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Density</td>
<td>1.00</td>
<td>1.75</td>
</tr>
<tr>
<td>The SAMI Cycle Framework</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Closeness</td>
<td>Academia-Market (13.55 cm)</td>
<td>Industry-Market (12.2 cm)</td>
</tr>
<tr>
<td></td>
<td>Academia-Industry (13.5 cm)</td>
<td></td>
</tr>
</tbody>
</table>

These changes in Table 6.4 reflect the changes in Lisa’s understanding of the relationship between state/government, academia, market and industry within the context of the SAMI cycle framework. Lisa’s results of the network analysis measures, which are centrality, degree connectivity, density and closeness (the total number of very close and close relationships), of the SAMI cycle framework indicate that there were improvements in Lisa’s understanding of the SAMI cycle framework.

Academia not being the central component in the post-interview might show that Lisa started to feel that other components of the SAMI cycle framework are as important as academia. This is evident in the increase in the degree connectivity, density and closeness of the components of the SAMI cycle framework. Each node’s degree connectivity increased as well as the degree connectivity of the SAMI cycle framework. This shows that Lisa’s understanding of the connection between the components of the SAMI cycle framework and the importance of each component within the framework increased. Furthermore, she started to make new
relationships in the post-interviews, such as the state/government-academia relationship.

Increase in the density indicates the increase in the number of connections between the components of the SAMI cycle framework. It may also be the precursor of the changes in the centrality and closeness. Therefore, it can be said that Lisa realised the connection between the components of the SAMI cycle framework better. The total number of very close and close relationships also increased from two to three. However, even though the industry and market did not have any relationship in the pre-interview, they had a very close relationship (12.2 cm) in the post-interview. This shows the increase in connection and importance of the industry and market to each other and the SAMI cycle framework. Furthermore, although the government was alienated in the pre-interview, it became connected and important to the SAMI cycle framework in the post interview.

While the connection and importance of academia to the other components and the SAMI cycle framework increased the least, the connection and importance of the industry to the other components and the SAMI cycle framework increased the most. This can be interpreted from the increase in its degree connectivity from one to three, density from 1 to 1.75 and closeness from one to two including one very close and one close relationship in the post interview. That is, Lisa started to realise a very close relationship between academia and industry after the intervention. Overall, Lisa was able to make numerically more and complex relationships in the post-interview, which shows an increase in Anne’s understanding.

To summarise the results of Anne’s, Mary’s and Lisa’s network analysis, the result of Lisa’s pre-interview gave similar results to Anne’s pre-interview. That is, they could only make a basic connection between academia, market and industry in a linear way in the pre-interview. However, they were able to link state, academia, market and industry to each other in a more complex way in the post-interview. The network analysis of Mary in Figure 6-5 showed that Mary could see all the relationships in the pre-interview. The reason for this would be that she might already have a good understanding of the interdisciplinary links. This is because Anne and Lisa have not completed a module(s) on entrepreneurship and/or economics at post-primary level and/or university, but Mary had. Thus, she might
be able to see the cross-curricular links better. However, even though Mary was able to see all the relationships in the pre-interview, she was of the opinion that state/government, academia and industry are more connected and important to each other. However, in her post-interview, she perceived them all connected to each other. All participants found academia central in the pre-interviews. In the post-interviews, all participants found the market more connected and important to the other components of the SAMI cycle framework. This can be interpreted from that the degree connectivity of market increased, and the market had at least one close relationship in all participants’ results. Furthermore, the industry had at least one very close relationship with the other components of the SAMI cycle framework in all participants’ post-interview network analysis results. This might show that participants found the industry very connected and important to the SAMI cycle framework after the intervention.

6.1.2. Changes in the PSTs’ Understanding During the Once-off PSTE

To determine PSTs’ understanding of the SAMI cycle framework during the once-off PSTE, both qualitative and quantitative data were collected from 50 PSTs; Anne, Mary, Lisa, Mark and P1 to P46. As the quantitative method, pre- and post-questionnaires were applied. 1st, 5th, 6th, 13th, 17th, 20th, 23rd, 24th, 25th, 27th, 28th, 29th and 30th statements in the questionnaires were targeting the SAMI cycle framework. As mentioned in Section 4.5.3, a null hypothesis and an alternative hypothesis were developed to answer the RQ-2. These hypotheses are:

Null Hypothesis =

\[ H_0 \text{3: There is no significant difference in the mean rank of PSTs’ understanding of the relationship between state/government, academia, market and industry (the SAMI cycle framework) before and after the research intervention.} \]
**Alternative Hypothesis**

Ha3: There is a significant difference in the mean rank of PSTs’ understanding of the relationship between state/government, academia, market and industry (the SAMI cycle framework) before and after the research intervention.

In order to determine which hypothesis to follow, a Wilcoxon signed-rank test was conducted. According to the results, the null hypothesis was rejected, and the alternative hypothesis was accepted because the “p-value” was smaller than .05 (p < 0.05). Therefore, the once-off PSTE elicited a statistically significant change in PST’s views on the state/government, academia, market and industry relationship -the SAMI cycle framework (Z = -3.503, p = 0.000). Indeed, participants’ median SAMI cycle framework score increased by 1.00 (Med_pre = 53.00) while mean was increasing by 1.63 (M_pre = 52.76). Furthermore, while 28 participants were showing an increase in their SAMI cycle framework score, 10 participants showed a decrease, and 11 participants showed no difference. That is, there was an increase in the majority of the participants’ (56%) understanding of the SAMI cycle framework and therefore how science works in society, while there was a decrease in almost a quarter of the participants’ (20%) understanding. When these participants were examined at individual level, 19 out of 21 participants (91%) were the same participants whose score either decreased or stayed the same both in the contemporary social aspects of NOS and the SAMI cycle framework. This result might propose that these participants were not engaged in the current study.

Furthermore, PSTs’ understanding of the SAMI cycle framework was also determined according to PSTs’ answers to each entrepreneurship-related statement on the questionnaire (1, 5, 6, 13, 17, 20, 23, 24, 25, 27, 28, 29, 30). Overall understanding of these statements increased (See Appendix 25 for further details). However, there was a decrease in the understanding of the 5th and 6th statements. These statements mainly target other social aspects of NOS, such as professional activities and social organisations and interactions (See Appendix 11). Therefore, this decrease might be related to participants’ understanding of professional activities and social organisations and interactions rather than the SAMI cycle framework.
6.1.2.1. Group Results of the Role-play Activity

To further examine participants’ (n = 50) understanding of the SAMI cycle framework, the qualitative data was collected during the role-play activity, which consisted of seven parts. The first four parts of the activity (See Appendix 12) involved role-playing with a scenario on the discovery of the “Haber-Bosch Process” including tasks to answer questions relevant to the SAMI cycle framework (“Question Time” parts). Part 5 and Part 6 of the activity (See Appendix 12) were targeting categorisation and diagram construction tasks on the SAMI cycle framework. In the diagram construction, participants were asked to draw a diagram explaining how science works in society (Please see Appendix 24 for the detailed role-play activity results of each group).

A notable finding was that the individual network analysis results of Anne, Mary and Lisa (See Figure 6-4, Figure 6-6 and Figure 6-8) illustrated almost the same diagram that they draw in Part 6 in the role-play activity. However, these network analysis figures illustrate different weight on different bilateral relationships. The similarity between the network analysis results of the post-interview in the continuous PSTE and what they reflected in the diagram they constructed in Part 6 of the role-play activity in the once-off PSTE supports each other.

All groups referred to the bilateral relationships in the SAMI cycle framework, such as academia-industry, academia-market, industry-market and government-academia relationships. For example, Group A explained the academia-industry relationship by stating that:

academics provide employees to work in industry, industry might be a career path, industry provides funds and scholarships and uses scientists’ methods/theories/inventions to improve large-scale operations.

(Grupo A, Question Time)

Concerning the relationship between academia and the market, Group B stated that:

science develops products that market wants. If market or scientist has an idea for a product, they consult each other.

(Grupo B, Question Time)
Group F explained the government - academia relationship by stating that:

the government can provide resources for the scientists or dictate what research is carried out and prioritise research/experiments. Scientists can provide new ideas/strategies/research that can benefit or change society.

(Group F, Question Time)

More complex relationships were evident in the diagrams that they constructed. For example, Group A constructed a diagram illustrating how science works in society, which is presented in Figure 33.

![Diagram](image)

Figure 6-9: Group A diagram illustrating how science works in society

As seen in Figure 33, Group A state/government, academia, market and industry are represented as they all are connected through the society.

The overall results indicated that participants had an understanding of the complex relationships between the different components of the SAMI cycle framework. Additionally, funding has been mentioned by all groups when they were explaining the relationships between state/government, academia, market and industry.
6.1.2.2. Individual Results of the Role-play Activity

In the role-play activity, Part 7 was completed individually by participants writing their opinion on the state/government, academia, market and industry relations. 45 participants answered the individual questions in Part 7 of the role-play activity.

In the individual written responses to the role-play activity, 42 participants were of the opinion that state/government, academia, market and industry are linked/connected, 35 of these participants believed that there was a stronger relationship between them, which was defined as interconnected, interlinked, interdependent, symbiotic, interwoven or complicated. For example, P26 emphasised this stronger relationship by making such comments as “they are interwoven. They are related to one another as they wouldn’t exist without each other”. 11 participants emphasised that state/government, academia, market and industry could not exist without each other. Two participants only mentioned the academia-market relationship, and one participant only mentioned the role of academia. Five participants did not answer the question.

Thus far, the participants’ understanding of the relationships in the SAMI cycle framework (state/government, academia, market and industry relationship) has been discussed. Additionally, the importance of this relationship was discussed by the participants. The primary importance of this relationship was defined as that the relationship between the state/government, academia, market and the industry helps each other to function to reach desired goals. Some examples explaining the reason for the importance of the state/government-academia-market-industry relationship are presented:

1. This relationship aids science to reach society.
2. This relationship facilitates to get the best possible benefit from each other.
3. If this relationship is missing a component others do not function correctly (do not thrive), they suffer, or they could not exist.
4. This relationship leads each other to make improvements and production.
5. The components of this relationship must work together to work successfully and achieve their desired goals.
6. Every component of this relationship blends together.
Each component of the relationship supports the scientific development and the growth of science.

In order to investigate its practicality, PSTs’ opinion on the inclusion of the SAMI cycle framework in the JCSS and its rationales were questioned. The results are discussed in the next section.

6.2. PSTS’ PERSPECTIVES ON THE INCLUSION OF THE SAMI CYCLE FRAMEWORK INTO THE JCSS

This section aims to answer RQ-2.1 - what are the perspectives of PSTs on the inclusion of the state/government, academia, market and industry relationship (the SAMI cycle framework) into the JCSS? Thus, this section examines the PSTs’ educational views on the inclusion of the state/government, academia, market and industry relationship (the SAMI cycle framework) into the science curriculum in Ireland. The science curriculum of junior cycle in Ireland is called Junior Cycle Science Specification (JCSS). The data which were collected to answer RQ-2 was analysed by the thematic analysis and Wilcoxon signed-rank test results in the continuous and once-off PSTE. While presenting the data to answer the research question, firstly the continuous PSTE and then the once-off PSTE results are presented in the following sub-sections.

6.2.1. PSTs’ Educational Views in the Continuous PSTE

This section presents the results relating to the inclusion of the SAMI cycle framework into the JCSS. In the continuous PSTE, all participants (Anne, Mary and Lisa) supported the inclusion of the SAMI cycle framework into the JCSS. This inclusion may motivate and engage students in science, increase students’ interest in science, improve their understanding of the interdisciplinary nature of science, and encourage students to contribute to the development of science. Mainly, participants referred to why the SAMI cycle framework should be included in the JCSS. Participants were of the opinion that learning about this relationship
can increase students’ understanding of the development of science and can benefit students in their future life.

For example, Lisa felt that this inclusion shows students how science has developed, and therefore students’ awareness of the different disciplines, such as industry and government, and their interlinks can increase.

Lisa stated that:

"this relationship is a good thing to include because students build up their background knowledge of the development of science. They don’t really think about the background idea. They will be aware of the interlinks behind the scientific development."

(Lisa, the post-interview in the continuous PSTE)

Students’ motivation, interest and engagement in science is highly important when learning the science content and how science works. Furthermore, students may be more engaged and motivated in science when they know about the future impact of what they are learning on their life. In this sense, Anne was supporting to teach this relationship to motivate and engage students in science by showing how learning about this relationship will benefit them in the future and stated that:

"teaching a small bit of it can motivate them (students) and engage them (students). Leaving Cert might be more useful because they learn how it is going to affect them."

(Anne, the post-interview in the continuous PSTE)

When participants were asked if they were teaching this topic how they would teach it, they suggested that they would show videos; conduct group work; apply “think, pair and share”; perform demonstrations; have a relevant visitor to the classroom; and perform storytelling. For example, Mary felt that science and business teacher can collaborate during the incorporation process while the SAMI cycle framework is taught in science classes, and stated that:

"it would be a good idea if the science teacher and the business teacher could work together to explain that to students. Maybe it's science teachers to take over one or two classes to show examples from a science perspective."

(Mary, the post-interview in the continuous PSTE)
Some concerns were also raised during the interviews which were again about the time constraints (having limited time for teaching science) and assessment. The concern about the assessment was that this topic is not included in the national exams and this can affect students’ and teachers’ attitudes towards learning this topic. For example, Mary felt that this topic is not assessed in the national state assessment, and therefore there is no need to spending much time to teach it.

I wouldn't be spending two or three weeks work on it trying to get students to understand this because at the end of the day they're not being tested on this but if it was to be incorporated than it's just gonna take a lot of time for the curriculum to change that way. I find like the driving force for the teachers and students is to get things covered for the test. It's all about the assessment on where is like if this is actually a part of the curriculum and it will need to be covered.

(Mary, post-interview in the continuous PSTE)

Furthermore, similar concerns were raised in the findings related to the contemporary social aspects of NOS.

6.2.2. PSTs’ Educational Views in the Once-off PSTE

This section presents the results from the questionnaires collected at the end of the once-off PSTE relating to the inclusion of the SAMI cycle framework into the JCSS. In the questionnaires, PSTs were asked their opinions on whether they think that it is important to incorporate the relationship between the state/government, academia, market and industry into the JCSS. While 38 participants (76%) were supporting this inclusion, 12 participants (24%) were not in favour of this.

As a result of the thematic analysis of participants’ justification of their answer, five themes emerged; (1) impact on future life/working life, (2) real-life applications through cross-curricular links, (3) understanding the world and society, (4) opportunities/interest in science, and (5) broadening students’ perspectives.

6.2.2.1. The impact on future life/working life

In this theme, participants addressed how this inclusion would affect students’ future/working life. Teaching the importance of the SAMI cycle framework might improve awareness of the importance of science and its impact on students’ future.
A number of participants were of the opinion that learning about this relationship can make students realise the importance of schooling (e.g. P5). P31 felt that “this inclusion might help them (students) to understand the importance of science and how it affects them”. P8 was of the opinion that this inclusion might change students’ (negative) views towards science and encourage students to consider science as a career option. Within this context, P8 stated that:

students may have a preconceived idea of what a scientist is and what their role is. To encourage students to possibly follow science as a career option they should be provided with as much info as possible in this relationship.

(P8)

Many participants were of the opinion that learning about this relationship can benefit students regarding potential job opportunities. For example, P11 and P19 were of the opinion that this will benefit students to get jobs they would like and succeed in their work life in the future. Some participants explained the reason for the importance of learning about this relationship by inadequate preparation for the work life. For example, P10 emphasised how poorly students are prepared for their work life and stated that:

students are currently poorly educated on this and people enter the working world with little knowledge on this. They (state-academia-market-industry) are interdependent and a hugely important part of industry into the future. When entering into any job you should have a foundation of this knowledge.

(P10)

This theme was also mentioned as the job opportunities and engaging students in science within the context of entrepreneurship in NOS and its findings in Chapter Five.

6.2.2.2. The real life applications

This theme primarily mentioned the understanding the applications of science in everyday life and making science more relatable to students’ lives. Participants felt that the inclusion of the SAMI cycle framework can make students realise how and where science is used in everyday life. Many participants referred to learning about the applications of science as one of the benefits of the inclusion of the SAMI cycle
framework. For example, P17 was of the opinion that “it helps students understand the applications of science better as it being a part of everyday life”. Lisa addressed that this inclusion can improve students’ understanding of the development of science by making them “aware of how scientific research/ products are developed”. P21 emphasised the importance of linking textbook knowledge with real life by stating that:

> it is important to make the connection between textbook knowledge and the workings of real world science to show how scientific knowledge is applied and used in everyday life.

(P21)

Many participants also referred to making science more relatable to life as one of the benefits of the inclusion of the SAMI cycle framework. For example, some participants (e.g. P13, P47) were of the opinion that this inclusion will make students aware of how science is used in society and how it is related to everyday life. Moreover, according to P6:

> academics need to be linked to the real world as much as possible to highlight the importance of what is thought in schools.

(P6)

Since the SAMI cycle framework involve interdisciplinary relationships, such as the relationship between academia, government and market relationship, teaching about this framework may improve students’ awareness of the interdisciplinary nature of science. Within this context, P41 and Mark mentioned the cross-curricular links of science by referring the interdisciplinary nature of science and real life relevance. P41 stated that:

> students will see the importance of science in different facets of the society and this can make science more relatable to students.

(P41)

Similarly, Mark stated in the questionnaire that this relationship should be included “in a practical way to show how society in general depends on many aspects”. This theme was also mentioned as making science more relatable to life and cross-
curricular links within the context of EOS and entrepreneurship in NOS and their findings in Chapter Five.

6.2.2.3. Understanding the world and society

Participants felt that learning about the framework may improve students’ understanding of the world and society, particularly as aspects of the framework (government/state, academia, market and industry) are a part of the global world. Within this context, while P3, P5 and P25 were addressing that this inclusion can help students to understand how the world works, P21 and P23 were of the opinion that this inclusion can help students to have a better understanding of science and society. For example, P36 stated that “it is important for students to know what’s going on in the world”. Likewise, according to P25:

students should have a basic understanding of how the world works. May not need a whole new subject but should be incorporated into the JCSS.

(P25)

The importance of understanding this framework was also mentioned by some participants. Having a basic (rudimentary/fundamental) understanding of how state, academia, market and industry are interlinked may contribute to the advancements in science and society. Within this context, for example, P1 stated that “without this relationship and everyone involved together, science and society would not be what they are today”.

This theme was also mentioned as social utility and the operation of science within the context of the social aspects of NOS.

6.2.2.4. The opportunities/interest in science

This theme includes the participants’ perception of how this inclusion can improve students’ interest in science and increase their awareness of the opportunities in science. Some of the benefits of the inclusion of the SAMI cycle framework in the JCSS may be that students’ interest, motivation and engagement in science would increase, and students can realise the different opportunities in science. Some participants felt that the inclusion of the SAMI cycle framework in the JCSS can
improve students’ interest and engagement in science. For example, P49 was of the opinion that “this inclusion helps students to value science subjects more”. Also, P12 felt that the relationships in the SAMI cycle framework include the government-academia relationship and the role of funding within these relationships, and learning about these relationships can improve students’ interest in science. P12 stated that:

it is helpful to make students interested in science more and for students already interested in science to understand the background behind funding. Students deserve to know how the government influences their education.

(P12)

There are many opportunities in science which can be funding-related, job-related and knowledge-related (e.g. discoveries). Many participants were of the opinion that this inclusion would increase the students’ awareness of the opportunities in science. For example, P42 stated that:

this (the SAMI cycle framework) should be included in the JCSS because it will show students many opportunities within science.

(P42)

This theme was also mentioned as students’ interest in science within the context of EOS, entrepreneurship and NOS and their findings in Chapter Five.

6.2.2.5. Broadening students’ perspective

This theme included the understanding the bigger picture of science and giving students a different view of science as the benefits of the inclusion of the SAMI cycle framework into the JCSS. Some participants were of the opinion that this inclusion is important for students to view science from different perspectives to have a holistic view of science.

For example, P15 felt that learning about the relationships in the SAMI cycle framework, such as the industry-market relationship, can make students realise the bigger picture of science. This is evident in P15’s statement:
it gives students the bigger picture of science by showing how the industry and market are linked together by the government and academic institution and explains how they impact their daily lives.

(P15)

Likewise, P6 and P29 were of the opinion that this inclusion can benefit students to understand and realise the broader picture of science. Some participants were of the opinion that this inclusion is important for students to view science from different perspectives and broaden their minds. For example, P34 and P40 were of the opinion that this inclusion can broaden the students mind to understand the world more. P40 stated that:

this can open students’ minds to see science is everywhere, it is not just behind closed doors in a lab.

(P40)

This above quote also refers to the everyday applications of science.

6.2.2.6. Concerns regarding the inclusion of SAMI cycle framework in the JCSS

Despite its mentioned benefits, 12 participants (24%) were against the inclusion of the SAMI cycle framework into the JCSS. Some of these participants were concerned that this relationship might be above the level of junior cycle students due to their age. Some participants felt that students do not have enough knowledge on science to link the components of the SAMI cycle framework. For example, P35 stated that “I feel the students do not know enough about the fundamentals of science to link it to these topics”.

It was suggested that science was a new subject/concept to students in junior cycle, without introducing more complex relationships. A number of participants were of the opinion that such concepts were more suited to senior cycle students who can deal with more complex issues and relationships. For example, P28 stated that:

while it would be useful, it might be better implemented in a leaving certificate curriculum as they will have a better broader understanding and be more aware of its relevance.

(P28)
Likewise, P31 stated that:

maybe at a leaving cert level when students are thinking about college. Too in-depth for junior cycle students and takes away from understanding scientific knowledge and practices, too much for 14 year olds.

(P31)

Some other participants believed that such concepts fitted more into other subjects rather than science. For example, P36 was of the opinion that this inclusion might be “more useful in Civil, Social and Political Education class in junior cycle”. Although 12 participants were against this inclusion in the junior cycle, the majority of them believed that such concepts fitted more into different levels, such as senior cycle and Transition Year rather than the Junior Cycle. For example, P37 suggested that “it should be included maybe at senior cycle when some students get jobs”. P28 supported the inclusion of this framework into the leaving certificate curriculum and stated that:

while it would be useful, it might be better implemented in a leaving certificate curriculum as they will have a better broader understanding and be more aware of its relevance.

(P28)

P31 also supported the inclusion of this framework into the leaving certificate curriculum and stated that:

maybe at a leaving cert level when students are thinking about college. Too in-depth for junior cycle students and takes away from understanding scientific knowledge and practices, too much for 14 year olds.

(P31)

While others believed that such topics should be explored in a cross-curricular manner and therefore not just included in one subject e.g. “maybe not as a stand-alone subject but it should be incorporated into subjects like business, science etc.” (P3).

Overall, although there were some concerns about the inclusion of the SAMI cycle framework into the JCSS, majority of participants supported this inclusion both in the continuous PSTE and once-off PSTE. Furthermore, many participants referred
to the same arguments with EOS, entrepreneurship and NOS while they were addressing the benefits of the inclusion of the SAMI cycle framework in the JCSS. This may support the claim in the current study on that the SAMI cycle framework is the conceptualisation of EOS, entrepreneurship and NOS. The next section presents PST’s experiences during the continuous and once-off PSTE.

6.3. PSTS’ EXPERIENCES OF THE CONTINUOUS AND ONCE-OFF PSTE

To determine PSTs’ experiences, Mark, Anne and Mary were interviewed about their experiences at the end of the once-off PSTE since they volunteered to participate in the interview. Three themes emerged relating the PSTs’ (Anne, Mary and Mark) experiences; the understanding of the cross-curricular links, educational applications that support/improve understanding and the challenges that participants faced with during the current study.

The understanding of the cross-curricular links

Within this context, Anne, Mary and Mark emphasised how their understanding of the links between various concepts in the study improved as a result of engaging in the current study. They indicated that, as a result of the intervention, they became more aware of the links between science, market and industry. Furthermore, they referred to EOS, entrepreneurship, NOS, and cross-curricular links between science and other subject areas. All participants began to think about science in terms of its cross-curricular links. For example, Anne stated that:

this study made me really think about everything. I thought that I had a basic level of understanding but I never thought about how much they (state, academia, market and industry) were all interconnected.

(Anne, the post-interview in the continuous PSTE)

Likewise, Mary explained how engaging in the study helped her to form greater cross-curricular links between different areas, such as science, business, industry and market, and changed the way she looks at the world. She stated that:
when I first read it that we need a concept statement and the crisis management, I was wondering what it has got to do with science. When you say entrepreneurship, industry, market and stuff like that, people tend to look towards business side of things rather than how they interlink. … As we went down through the different phases I got to see the development of this research and understood why everything is there. … It was like a map. I can really see how each of them are really interlink the each other and how they are related. I learned that definitely.

(Mary, the post-interview in the continuous PSTE)

Mark addressed the cross-curricular links by referring the relationship between different contexts, such as the government-industry-society relationship, and stated that:

it got people (participant PSTs) thinking the way of science; it is not always good, it can be used for bad as well. … I suppose it also got them (other participants) to think about the way of science like you 've got the industry, you've got the government and you've got the society and how they are interlinked and they affect each other.

(Mark, the interview in the once-off PSTE)

Furthermore, Mary also felt that having an understanding of the greater cross-curricular links between economics, entrepreneurship and science helped her to understand how science works in everyday life. She started to view science from a different perspective and referred to the social aspects of science, such as professional activities (e.g. attending conferences), by stating that:

I see science in a different perspective now. Scientists are not in a little bubble to themselves inside their offices or wherever locked up, doing experiments. They are more integrated and involved in different aspects of society; like they present at conferences.

(Mary, the post-interview in the continuous PSTE)

It is notable that Anne and Mary emphasise the interconnection between different areas, such as entrepreneurship, EOS and science. This is an important finding since this study aims to conceptualise EOS, entrepreneurship and NOS. Therefore, it might be said that participants’ understanding of the relevance of EOS, entrepreneurship and NOS, and the SAMI cycle framework relationships were increased during the continuous PSTE.
Educational applications that support/improve understanding

There were four educational approaches that participants identified as supporting/improving their understanding: story-based group discussion activity, concept statement activity, crisis management activity and role-play activity.

In the *story-based group discussion activity*, participants mainly emphasised the interdisciplinary links and learning about social-institutional system. Interdisciplinary links that science has refer to the link of science with different concepts, such as industry and government. For example, Anne mentioned the interdisciplinary links by stating that “it was interesting to read about how the research affected different areas like industry”. Mary also referred to this by stating that:

it's (the story-based group discussion activity) good because you'd read down through the story and you wouldn't think much of it. When you give it a thought on what you actually trying to do or trying to figure out or trying to understand what points to make, you do begin to see the links between different aspects because the story develops this like a map.

(Mary, the post-interview in the continuous PSTE)

Furthermore, all participants mentioned that they learned about science as a social system. For example, Anne stated that:

I learned what social system is because we were debating and backing our opinions to understand what it was about rather than dealing with a definition on a page.

(Anne, the post-interview in the continuous PSTE)

It was suggested that the story-based group discussion may make students look at an issue from other people’s perspectives. For example, Mary indicated that she learned about looking at a situation from different perspectives. While she was talking about her experience of story-based group discussion she repeatedly mentioned how she was thinking about what points others made and how she can support her claim.

In *the concept statement activity*, participants felt that they learned about exploring options and alternatives as relevant to creativity, realising different perspectives when working with others and the interdisciplinary links, particularly the link between entrepreneurship and science. Participants were referring to exploring
options and alternatives when they need to find a solution to an issue. While Anne was mentioning how difficult it was to come up with ideas and think what to do with them, Mary addressed that they tried different approaches when working on the task and argued the problems and their solutions and stated that:

as the product developed, we came across more and more hurdles. It was a good product but we had to get the lecturers on board and we had to get the universities on board, we had to get all the books and publishers on board as well. As we developed it further, we kind of did come across a few different ones like the industry or the company making the product has to give recognition to the academic institutes.

(Mary, the post-interview in the continuous PSTE)

Moreover, participants started to be aware of the other people’s perspectives when working in group, which was also emphasised in the story-based group discussion. For example, Anne realised different perspectives of people when working in group, which is evident in her statement:

it was I suppose difficult working in a group. I'd see that there was one way to answer the question but other girls would see a different way that I never even thought of.

(Anne, the post-interview in the continuous PSTE)

Moreover, Mary was referring to both learning about different perspectives of people and interdisciplinary link between science and entrepreneurship when she stated that “entrepreneurship and different values and ideas of other people”. Even though Mary was unable to understand the relevance of concept statement with science at the beginning of the continuous PSTE, she was able to understand their relevance later on. This is evident in that while she was stating at the beginning that “when I first read that we need a concept statement and the crisis management, I was wondering what it has got to do with science”, then she stated later on that “I can really see how each of them are related”. Mary was also able to see the connection between the concept statement and crisis management activities. Within this context, she stated that:

once we understood what you were getting at, that was very good. Then I found the scenario (crisis) very good to identify the hurdles in the project (concept statement) and thought of different solutions.

(Mary, the post-interview in the continuous PSTE)
There was only one recommendation related to the concept statement activity. Mary recommended that it would be more beneficial if they actually met company managers or relevant business people to talk about their business idea. This might be applied in an extended project with a certain budget.

In the crisis management activity, participants learned about working with others, making considered decisions by listening to different perspectives, exploring different solutions by trying different approaches and the interdisciplinary links, particularly the links between science and economics.

For example, Mary explained her experience of when she started to think from different people’s perspectives by stating that:

> it was very hard I suppose because we're not actually communicating with any publishers so you don't really know their response to it. You can just assume that what we want and what we give to them is gonna be ok on their perspective.

(Mary, the post-interview in the continuous PSTE)

Participants mentioned exploring different solutions by trying different approaches. For example, Anne stated that “We were trying to come up with different solutions to the problem you gave”. Furthermore, Anne also mentioned the importance of receiving funding and making considered decisions through collaborative discussions and stated that:

> I learned that money is a big issue like; how are you going to get them, how are you going to convince that your idea is better than others ideas how are you going to get resources, how are you going to organise the stuff? I learned about economics and difficulty of getting money.

(Anne, the post-interview in the continuous PSTE)

Finally, Anne recommended to spend more time on the crisis management activity. She was of the opinion that when more time is spent to explain and explore the possible solutions to the crisis.

In the role-play activity, the aim was to improve participants’ understanding of the elements of the SAMI cycle framework and their relationship. Referring to the role-play activity, all participants (Anne, Mary and Mark) found the role-play activity
in the once-off PSTE interesting, engaging an effective way of teaching a topic. For example, Mark felt that the real science story in the role-play activity was very interesting and made them think about how science works:

I think the activity was very interesting. As we were doing the story we were coming to the realisation that it's moving on and there is more to this. I think the story really got people to think about the reality and how things work.

(Mark, the interview in the once-off PSTE)

Furthermore, participants were engaged in the activity when they were performing their role-play and answering the “Question Time” cards. For example, Anne felt that she was very engaged in the activity due to using her imagination and thinking about the next steps. Also, she had fun when she was pretending to be someone else, which is evident in her statement:

I thought that was good that you had to imagine who you were and what you were going to do for your next step because even though reading it is good when you actually have to pretend to be the person you can put some fun into it and get you thinking about it more.

(Anne, the interview in the once-off PSTE)

Mary also found the role-play activity “very cohesive” and addressed that “it made more sense because of what we've done last semester”. Mary’s this quote also compares the continuous and once-off PSTE. She comprehended the role-play activity in the once-off PSTE quicker due to her involvement in the continuous PSTE. Furthermore, Anne compared the continuous PSTE and the once-off PSTE and stated that she felt “more involved in the role playing than the story-based group discussion” and addressed that:

I like the role playing because each person had a different part (role). In the first one (story-based group discussion) you were just reading it through. This (role-play activity) is more interesting to see. You could see it better here.

(Anne, the interview in the once-off PSTE)

Mark and Mary mentioned the challenges involved in the role-play activity in the once-off PSTE. For example, Mark found this activity challenging due to the background of PSTs. He suggested to improve this activity by assigning a facilitator/guide for each small group. This quote was pointing to one of the challenges faced with while conducting the activity. Even though there were 10
groups there were only three instructors in a big lecture hall. Therefore, it was challenging to keep up the same pace within all the groups. Assigning an instructor to each group might be one of the suggestions. Mary also addressed some challenges in the activity, such as discussing about ethical issues (scientific ethos and social values question in Question Time 4), but she also mentioned that she learned about respecting different perspectives when they were discussing about the ethical issues.

Overall, Anne and Mary were both agreed on that the continuous PSTE was more effective in learning about EOS and entrepreneurship and their relevance to each other. However, Anne, Mary and Mark also found the role-play activity more engaging due to being more active and interesting, and they referred to the interrelations between the components of the SAMI cycle framework more often in the role-play activity.

6.4. CONCLUSION

This chapter aimed to answer the RQ-2 and RQ-2.2, which were related to the SAMI cycle framework and PST experiences. The findings presented in this chapter showed that there were improvements in participants’ understanding of the SAMI cycle framework and the majority of participants supported the inclusion of this framework into the JCSS. Furthermore, participants found the continuous PSTE more effective than the once-off PSTE. In the continuous PSTE, the results of thematic analysis and network analysis, which was conducted through UCI Net, showed improvements in all participants’ understanding of the SAMI cycle framework. The number of relationships that Anne, Mary and Lisa could make relating the SAMI cycle framework were increased. Concerning thematic analysis, three main themes emerging in the data were presented; moving from fragmented to a whole view of the SAMI cycle framework, understanding of EOS and understanding of entrepreneurship. Similar themes also emerged in Chapter Five. Additionally, all participants supported the inclusion of the SAMI cycle framework in the JCSS to increase students’ understanding of the development of science and can prepare students for their future career.
In the once-off PSTE, two hypotheses were developed. The Wilcoxon signed-rank test was conducted through SPSS and results showed the once-off PSTE elicited a statistically significant change in PST’s views on the state/government, academia, market and industry relationship -the SAMI cycle framework (Z = -3.503, p = 0.000). Since “p-value” was smaller than .05, the alternative hypothesis was accepted. The majority of participants were supporting the inclusion of the SAMI cycle framework in the JCSS. However, the number of participants supporting the inclusion of entrepreneurship and EOS in the JCSS was slightly higher than the number of participants supporting the inclusion of the SAMI cycle framework. Some of the main benefits of this inclusion were realising the real-life applications of science and the opportunities/interest in science.

In the next part – PART THREE, the results presented throughout Part Two are discussed and the study is concluded.

25 Null Hypothesis (H₀): There is no significant difference in the mean rank of PSTs’ understanding of the relationship between state/government, academia, market and industry before and after the research intervention.

Alternative Hypothesis (Hₐ): There is a significant difference in the mean rank of PSTs’ understanding of the relationship between state/government, academia, market and industry before and after the research intervention.
PART THREE:
DISCUSSION AND CONCLUSION
CHAPTER SEVEN: DISCUSSION

Findings from the current study indicated an increase in PSTs’ understanding of the contemporary social aspects of NOS and the SAMI cycle framework in the continuous PSTE and the once-off PSTE. Based on the changes in PSTs’ understanding, three main discussion points, which emerged from the data, will now be discussed. Firstly, including such concepts in junior cycle science may support the development of a more holistic understanding of science among students. Secondly, these concepts benefit students in a number of ways, including but beyond economic aspects. Thirdly, there are implications of this inclusion for the JCSS, pre-service teacher education and science education. Therefore, in this chapter, the findings from the contemporary social aspects of NOS and the SAMI cycle framework and their possible implications in the JCSS, the pre-service teacher education and science education are discussed.

7.1. FACILITATING PSTS’ UNDERSTANDING: MOVING FROM FRAGMENTED TO HOLISTIC UNDERSTANDING

This section aims to discuss the contribution of the inclusion of the contemporary social aspects of NOS –EOS and entrepreneurship- and the SAMI cycle framework in science education to improve students’ holistic view of science. At the start of the current study, PSTs showed a fragmented understanding of the contemporary social aspects of NOS and the SAMI cycle framework, such as viewing scientists and entrepreneurs as entities that cannot be combined or viewing only the academia and industry relationship in the SAMI cycle framework. Having engaged in the study, PSTs began to show signs of a more holistic understanding. Nonetheless, evidence of this fragmented understanding remained even in the post-interviews.
In terms of the fragmented understanding, PSTs viewed entrepreneurship separate to what scientists do. That is, PSTs perceived entrepreneurs and scientists as separate entities, and they did not mention anything relevant to the concept of the “entrepreneurial scientists”. PSTs also showed a fragmented understanding when they perceived that entrepreneurship and EOS related specifically to business studies and not to science. The idea of teaching science by utilising entrepreneurship did not occur to these PSTs prior to the PSTE.

A fragmented understanding of the SAMI cycle framework was also indicated by PSTs at the beginning of the current study. PSTs perceived the state/government separated than the other components of the SAMI cycle framework. This was evident in that the government did not come up in either thematic analysis or network analysis. Even the emerging relationships between the components of the SAMI cycle framework were basic dual relationships, such as academia-industry relationships, rather than trio and quartet relationships. Not being able to realise complex relationships may also suggest a fragmented understanding. While this fragmented understanding of students is not desired (e.g. Erduran and Dagher 2014a, 2014b; Gustafsson-Pesonen and Remes 2012), there are possible reasons why students, having been in the Irish education system for so long, may form a fragmented understanding of knowledge (Beane 1995; Smyth and Banks 2012). One of the reasons might be the type of the curriculum applied in Ireland, which is that students are exposed to content/knowledge in discrete subjects. According to Beane (1991):

> the school constructs and organises a curriculum that is an artifice of life and, in that sense, an obstacle to education that has unity and meaning.

(Beane 1991, p.9)

According to Berglund and Gericke (2016), even though applying a separated perspective in education, in the form of discrete subjects, might improve students’ understanding of the concepts; it might provide fewer opportunities to view something from different perspectives. Furthermore, in their study, they found that when separate perspectives were applied in the class, students did not consider the contradictions inherited within the concepts, such as environmental, social and
economic dimensions of the sustainable development but rather viewed these concepts separately.

As the current study continued, signs of more holistic (or less fragmented) understanding of the concepts began to emerge amongst participants. For example, at the beginning of the current study, PSTs referred predominantly to funding of science as well as giving a limited reference to the place of scientists in industry, which are in the scope of EOS. However, at the end of the study, PSTs also referred to commercialisation of science in addition to funding of science and the place of scientists in industry. The role of technology was also mentioned by PSTs as an extra scope. Based on the findings, technology was proposed as a new addition to the scopes of EOS in NOS, as discussed in the future studies section in Chapter Eight. This realisation of the relationships between science and the different accounts, such as industry and market, may show that PSTs started to perceive science more holistically. According to Erduran and Dagher (2014):

> the purpose of the FRA as applied in educational settings is neither to teach students individual ideas nor to teach them specific philosophical doctrines about science but rather to promote holistic and contextualized understanding of science.

(Erduran and Dagher 2014, p.25)

Therefore, due to supporting the contextualised understanding of science the inclusion of the contemporary social aspects of NOS and the SAMI cycle framework might contribute to the improvements in holistic understanding of science.

Some participants were of the opinion that the components of the SAMI cycle framework have a symbiotic relationship. Symbiotic relationship refers to a close and long-term interaction between two different organisms. In this relationship, there can be a two-sided benefit or one side benefit, or one harms the other one. When this perspective is applied to PSTs’ view, it may show that these PSTs are aware of the negative or positive interaction between the components of the SAMI cycle framework. Similar to the current study, Berglund and Gericke (2016) found that when an integrated perspective was applied in the class, students exposed and highlighted the contradictions inherited within the concepts, such as
environmental, social and economic dimensions of the sustainable development. Realising the positive and negative relationships between these components is significant since realisation of the relationships including contradictions might be a precursor of a holistic understanding (Berglund and Gericke 2015).

Moreover, understanding science as a whole requires the complementary, sometimes contrasting perspectives, and improving students’ awareness of the failures and errors in science is of importance (Allchin 2011). Therefore, the inclusion of the contemporary social aspects of NOS and the SAMI cycle framework might increase students’ awareness of the contradictions between different disciplines such as EOS, science and entrepreneurship, and therefore might increase the holistic understanding in science. Furthermore, this shows that this study is not to present EOS, entrepreneurship and the SAMI cycle framework as a perfect addition but to increase people’s awareness on the possible outcomes of their inclusion in NOS and science education.

Another sign of a more holistic understanding of the subject matter, following engagement in the intervention, may be the participants’ references to “entrepreneurial scientists”. That is, they started to combine the characteristics and scientists together rather than viewing them as separate entities. Some PSTs also indicated more and complex relationships between the components of the SAMI cycle framework. This was evident in both thematic analysis and network analysis. Additionally, PSTs started to internalise EOS and entrepreneurship within the SAMI cycle framework when they were explaining how science works in society. That is, they started to realise the integration of different concepts to each other. Integration is important to reassemble fragmented pieces of a discipline of knowledge to have a holistic understanding (Beane 1995). During the integration of the fragmented pieces of a discipline of knowledge, from an interdisciplinary perspective, boundaries of subject areas are not desired (Broggy et al. 2017).
At the end of the study, evidence of the fragmented understanding of the concepts continued to exist. The issue of fragmentation may not only relate to specific subjects and disciplines of knowledge but also it is far-reaching in the education system. The possible factor causing the fragmented understanding may be found in the Irish education system. Gleeson (2010), for example, believed that such fragmentation is a common feature of the Irish education system. Likewise, the Teaching Council of Ireland (2011) stated that:

despite research, reports and restructuring of sections within the Department of Education and Skills, the problem of fragmentation of teacher education has remained significant in Ireland with insufficient linkages being made between the stages of the continuum.

(Teaching Council of Ireland 2011, p.8)

Therefore, it is understandable that a fragmented perspective would still remain in the post-interview, as the PSTs came through about 16 years in an education system (primary, second and third level) where knowledge is fragmented, divided into sections and packaged as discrete forms of knowledge (Beane 1991, 1995; Gleeson 2010; Goodson 1992). Expecting a complete change in 16 years’ understanding and perspective in a very limited period of time may be unreasonable. However, the changes in the findings seem hopeful. Emanation of a holistic understanding can take some time and require continuous practice in a subject area, but it can be achievable. Within this context, the inclusion of the contemporary social aspects of NOS and the SAMI cycle framework in science education might support increasing students’ holistic understanding of science. This is because these concepts are developed within and across the extended FRA, and Erduran and Dagher (2014a, 2014b) claimed that the extended FRA brings different aspects of science, such as the scientific practices and the social contexts of science, in a purposeful and holistic way rather than in a disconnected and fragmented way. In this sense, Erduran and Dagher (2014b) stated that:

the model (the extended FRA) unifies the various categories of NOS into a meaningful whole. It offers a narrative where the aims and values, the methods, the practices, and the social contexts of science are all related to each other in a purposeful and unified fashion, rather than presented in disconnected fragments that might appear arbitrary from the learners’ point of view

(Erduran and Dagher 2014b, p.349)
Dagher and Erduran (2017, p.47) believed that “understanding the NOS in science education requires an appreciation of a collective and holistic account of science”. If the holistic understanding of students in NOS is desired, due to the potential contribution of this inclusion to students to view science as a whole, the contemporary social aspects of NOS may be included in NOS and science education to support the holistic understanding of science.

Overall, the potential and perceived benefits and contributions of the inclusion of the contemporary social aspects of NOS and the SAMI cycle framework have been discussed across the data and the literature.

7.2. PSTS’ PERCEIVED BENEFITS AND CONCERNS OF THE INCLUSION AND IMPLICATIONS FOR THE JCSS

This section aims to discuss the PSTs’ perceived benefits and concerns of the inclusion of the contemporary social aspects of NOS –EOS and entrepreneurship- and the SAMI cycle framework in science education and the JCSS, and potential implications for the JCSS.

7.2.1. PSTs’ Perceived Benefits of the Inclusion of the Contemporary Social Aspects of NOS and the SAMI Cycle Framework for the JCSS

PSTs identified a variety of benefits to including these concepts in science education and the JCSS. The common benefits identified by participants were that including these concepts:

1. contributes to the social and economic development of a country
2. contributes to the future career including providing job opportunities
3. enhances students’ understanding of the politics of the government
4. makes science more relatable to life
5. increases students’ understanding of the interdisciplinary nature of science and developing the bigger picture of science
6. increases students’ motivation and confidence in science
7. contributes to the society by increasing social utility and understanding of the science-society relationship.

Each of which are now explored within the literature.

Concerning the economic benefits, PSTs addressed that this inclusion could benefit the social and economic development of a country. The impact of EOS and entrepreneurship on the social and economic development of countries was also discussed in different studies (Amos and Onifade 2013; Irzik 2007, 2013; Mirowski and Sent 2008). Particularly, the EOS and entrepreneurship literature addressed that EOS and entrepreneurship are money, career or economic development driven (Amos and Onifade 2013; Birdthistle et al. 2007; Etzkowitz 2008; Irzik 2007, 2013; Mirowski and Sent 2008). Amos and Onifade (2013) presented similar findings to the findings of the current study. They found that the pre-service teachers felt that there is a need in the teacher education programmes for entrepreneurship education to contribute to the social and economic developments of the countries. Furthermore, Kelly (2007) argued the scientific literacy and mentioned the relevance of the social and economic development with it. Within this context, Kelly (2007) advocated that the countries need scientifically literate responsible citizens who are concerned with their role in the social and economic development of their country.

PSTs felt that the inclusion of the contemporary social aspects of NOS and the SAMI cycle framework could support students’ future career by (a) improving their economic and entrepreneurial skills, knowledge, understanding and/or attitude, (b) providing students new job opportunities and encouraging the students to create their job by starting their business and (c) preparing students for working life. PSTs suggested that improving those skills, knowledge, understanding and attitude can encourage students to start a business in the future and may result in future success and confidence in their future job. The benefits of learning about EOS and entrepreneurship on the future career and the job opportunities were also discussed in different studies (Achor and Wilfred-Bonse 2013; Birdthistle et al. 2007;
Etzkowitz 2008; Stephan 1996). For example, Bruyat and Julien (2001) stated that in the last decades, entrepreneurs have created the vast majority of new jobs which provided a considerable number of job opportunities.

Furthermore, according to Etzkowitz (2008), commercialisation of science, which is accepted as one of the scopes of EOS in the current study, contributes to increasing innovation facilities of the universities and to enabling new job opportunities. It is not surprising then that the inclusion of entrepreneurship and EOS in NOS and science education may contribute to the future careers of students and increase the job opportunities for them. Furthermore, the SAMI cycle framework might also increase “students’ awareness of self-employment as a career option and the possibility of starting their own business” (Kaya et al. 2018b, p.472) since this framework is the conceptualisation of EOS, entrepreneurship and NOS. The increase in job opportunities also supports the “social wealth” (Venkataraman 1997), which also refers to the social and economic development of a country and the social utility.

PSTs felt that the inclusion of the contemporary social aspects of NOS and the SAMI cycle framework could improve students’ understanding of the politics of a country/government. The politics of the government refers to the political power structures in the extended FRA (Erduran and Dagher 2014a), the significance of which was presented between Chapter One and Chapter Three, and the place of state/government in the SAMI cycle framework was defined as indispensable by the majority of PSTs in the once-off PSTE. PSTs identified that improving understanding of the politics of the country/government is important due to the relationship between government, industry and market, the dictation of market by the government, and the relevance of technology to EOS and the government. The literature also indicates the dictation of the market, research and the scientific industry by economics and the government. For example, Kaya et al. (2018b) stated that:

the distribution of grant aid/money is determined by the role of government, which may support or limit the various scientific domains and possibly identify successful commercialization of technology.

(Kaya et al. 2018b, p.461)
Furthermore, the relationship between the government, industry and market was discussed, for example, by Erduran and Mugaloglu (2013). Erduran and Mugaloglu (2013, p.2411) stated that “both governments and private firms provide funding for the development of scientific knowledge in genetics”. There is also research presenting the relevance of technology to EOS and the government (e.g. Mirowski and Sent 2008). If technology is important to provide sustainable economic growth (Mirowski and Sent 2008), which is one of the main goals of governments, then, it can be said that scientific knowledge and technology are within the interest of governments (Erduran and Mugaloglu 2013). Therefore, increasing the awareness of the politics of the government (i.e. political power structures) in science education is important since this awareness may contribute to creating responsible citizens who take responsibility for and have justice in their actions (Erduran and Dagher 2014a). Furthermore, in this study, the importance and relevance of technology was mentioned by PSTs within the context of the politics of the government (Pedretti and Nazir 2011) and EOS, which is discussed in the future studies within the scopes of EOS in NOS.

PSTs suggested that this inclusion could make students see science as more relatable to life. Furthermore, they felt that due to this inclusion, student may realise everyday applications of science and appreciate where things come from. These benefits were also emphasised in the literature. For example, DES (2015) emphasised the importance of “applying science in everyday lives” (p.5) and “understanding the origins and impacts of social, economic, and environmental aspects of the world” (p.6). Realising everyday applications of science and learning about how a scientific idea can be turned into an everyday practice could make students appreciate where things come from. Additionally, according to Kaya et al. (2018b), realising how science is utilised and the applications of science in everyday life may possibly facilitate students’ understanding of how science relates to science and society. Through showing the everyday applications of science and the role of science in daily life, science could also be imbodied, and the abstract concepts of science could be turned into concrete examples.

PSTs believed that students’ understanding of the interdisciplinary nature of science could be improved and a bigger picture of science could be developed with the inclusion of EOS, entrepreneurship and the SAMI cycle framework. They were
also of the opinion that learning about the SAMI cycle framework could encourage students to contribute to the development of science by making them aware of how scientific research/products are developed. Within the context of the SAMI cycle framework, many PSTs also identified that this inclusion could increase students’ awareness of different disciplines. This is not surprising due to the interventions bringing different domains together, such as EOS, entrepreneurship and science. Kaya et al. (2018b, p.467) mentioned the interdisciplinary approach to science education by mentioning that the contemporary social aspects of NOS and the SAMI cycle framework can provide “a greater understanding of cross-curricular links of science”. An interdisciplinary approach to science teaching aims to facilitate a better learning experience for students by crossing subject boundaries (Broggy et al. 2017). Furthermore, interdisciplinary approach leads the process of innovation in education (Bauerle et al. 2014). Therefore, improving students’ understanding of cross-curricular links and interdisciplinary perspective might make students look at science from different perspectives and realise the bigger picture of science.

PSTs indicated that the inclusion of EOS, entrepreneurship and the SAMI cycle framework could increase students’ motivation, interest and confidence in science. This might result in making science easier to learn for students. The literature also demonstrated that the inclusion of economic perspectives (i.e. EOS) in NOS may motivate students by making science more interesting, exciting and engaging (Allchin 2011; Clough 2011; Erduran and Mugaloglu 2013; Kaya and Erduran 2016; Kaya et al. 2018a, 2018b). According to Deveci (2016) and Deveci and Cepni (2014), entrepreneurship in science teacher education can increase motivation and interest in science classes. Furthermore, Kaya et al. (2018a, 2018b) suggest that the inclusion of the SAMI cycle framework in science teaching can support the development of more authentic and engaging science classes. Increasing interest, curiosity and confidence in science might also encourage students to make discoveries in the future. Furthermore, developing a lifelong interest in science by providing enjoyment in the learning of science is one of the aims of science in junior cycle.

PSTs suggested that the inclusion of the contemporary social aspects of NOS and the SAMI cycle framework may encourage students to turn scientific discoveries
into socially beneficial products, satisfy the need in the society and make products available for public use, which, in turn, have a potential to benefit society and contribute to the development of science. They also felt that by this inclusion, students could have a better understanding of how the world works and science and society relationship. When students are learning to turn discoveries into products and making them available in the market they might also be learning to convert/implement an idea into practice. The importance of social utility in NOS and science education was also discussed in a number of studies (Erduran and Dagher 2014a; Irzik and Nola 2014; Kaya and Erduran 2016). For example, according to Erduran and Dagher (2014a, p.142) “increased attention to the social utility of scientific research is necessary for garnering public support”. Irzik and Nola (2014) believed that social utility is broadly understood as improving the quality of health and life of people and contributing to economic development. They advocated that:

the social legitimation of science today depends crucially on its social utility. Social utility then serves as an important social goal of science.

(Irzik and Nola 2014, p.12)

Viewing the social utility as one of the goals of science, Kaya and Erduran (2016) found a reference to social utility in the Turkish science education curriculum. Social utility was examined within the context of the social values of science, which is one of the components of the SIS of science (Erduran and Dagher 2014a). Kaya et al. (2018b) also highlighted the significance of focusing on the social values of the scientific research more than its economic benefits. This focus might be achieved by increasing students’ awareness of the social and economic issues in science. Furthermore, it was also advanced and argued in the literature review of the current study (Chapter Two and Chapter Three) that the SAMI cycle framework aims to explain how science works in society; and therefore the science and society relationship. When advancing this argument, the relationship between the state/government, academia, market and industry was explained within society. It was suggested that performing this integration might contribute to “the improvement in the students’ interpretation of the relationship between science and society” (Kaya et al. 2018b, p.475).
Some other benefits were identified by PSTs regarding specifically the contemporary social aspects of NOS, for example:

1. Providing equal opportunities to all students
2. Learning to convert/implement an idea into practice
3. Increasing awareness of the social and economic issues in science
4. Encouraging students to share their ideas

Thus far, some of the benefits emphasised by PSTs in the current study have been discussed based on the literature. Even though contributing to a country’s social and development and understanding the impact of social and economic aspects of the world are involved in the intended learning outcomes of the education (DES 2015), this alone might not be enough to support this inclusion in NOS and science education since it is a very specific benefit. Some issues might also emerge from viewing the benefits of the inclusion of EOS and entrepreneurship only from an economic perspective. For example, one of the primary aims of science is the pursuit of knowledge driven by curiosity (DES 2015; Kaya et al. 2018b). Focusing on only economic benefits may result in science driven by economics rather than curiosity. Financial relationships in an economic-driven research can affect different aspects of scientific investigations, such as study design and data analysis (Resnik and Elliot 2013).

Additionally, science in junior cycle encourages students to develop (1) a lifelong interest in science by providing enjoyment in the learning of science, (2) scientific literacy in science issues relevant to society, the environment and sustainability, (3) a scientific mind fostering investigation, imagination, curiosity and creativity in solving engaging, relevant problems, (4) reasoning and decision-making abilities, and (5) understanding of the origins and impacts of social, economic, and environmental aspects of the world (DES 2015). When the focus of learning is only on the economic benefits, these aspects may be underdeveloped. Nonetheless, once students’ awareness of these possible issues are increased starting by their education, these issues might be decreased or even eliminated before they get bigger. Since the PSTs’ perceived benefits of the inclusion of the contemporary social aspects of NOS and the SAMI cycle framework are also in the literature, the implications of these concepts in the JCSS are discussed in the following sections.
However, before discussing the implications for the JCSS, concerns regarding this inclusion are discussed in the next section.

7.2.2. PSTs’ Concerns of Integrating New Concepts in the JCSS

The results indicated that PSTs had concerns relating to the inclusion of the contemporary social aspects of NOS and the SAMI cycle framework in the JCSS. Three main concerns emerged, which were (1) students are taught these concepts already within different school subjects (2) the suitability of these concepts to the age of junior cycle students and (3) these concepts do not form part of the state assessment. These concerns are discussed in the following paragraphs.

Firstly, PSTs were of the opinion that the contemporary social aspects of NOS and the components of the SAMI cycle framework are already taught in different subject (e.g. business studies) or at different education levels (e.g. senior cycle, Leaving Certificate). Politics may be taught in the subject “civil, social and political education” at junior cycle or entrepreneurship may be taught in the subject “business studies” at junior and senior cycle. However, the implications of the current study does not suggest teaching pure content knowledge relating to EOS, entrepreneurship and the SAMI cycle framework. The current study suggests the inclusion of these concepts by weaving them throughout the JCSS in a holistic way. For example, the relevant understanding, knowledge, skills and attitudes of these concepts to science could be integrated in the JCSS rather than teaching pure EOS, entrepreneurship and the SAMI cycle framework knowledge. Additionally, PSTs’ focus on the content knowledge of these concepts (i.e. EOS, entrepreneurship and the SAMI cycle framework) and their separation from science shows a fragmented understanding, as discussed in Section 7.1.

Secondly, PSTs were of the opinion that the concepts of the contemporary social aspects of NOS and the components of the SAMI cycle framework may not be pedagogically suited and may cause confusion due to the age of the students at junior cycle. Even though there is research supporting the inclusion of entrepreneurship at all levels of education (Kleppe 2002), the results of the current
study revealed slightly different findings. The majority of PSTs supported to include these concepts at the second-level education and above. It was suggested that these concepts are above the junior cycle students’ level due to their age. However, the concern regarding the age of the students contradicts the previous concern claiming that these concepts are already taught at junior cycle and senior cycle. This is because PSTs claimed that politics, entrepreneurship and economics are already taught at junior cycle. If these concepts were above their level they would not be taught at junior cycle already. Furthermore, the SAMI cycle framework illustrates the state/government, academia, market and industry relationship by conceptualising EOS, entrepreneurship and NOS. In this sense, while state/government refers to the politics, market and industry refer to EOS and entrepreneurship, and academia refers to science. Therefore, these concepts (state/government, academia, market and industry) are actually already introduced at the junior cycle in different subjects (e.g. civil, social and political education, business studies) even if it is in a fragmented way.

Additionally, this concern may be discussed from a pedagogical perspective. Some PSTs were of the opinion that the contemporary social aspects of NOS and the SAMI cycle framework may be abstract and therefore difficult to learn. However, Piaget’s Cognitive Theory claims that children at the age of 11-14 change their stage from concrete operational to formal operations (Piaget 1952). That is, people start being able to learn abstract concepts and reasoning, and apply one concept into different contexts when they are 11 years old and over. Some PSTs also felt that the inclusion of these concepts can make science complicated and students might get confused. However, according to Bloom’s Taxonomy, knowledge and comprehension are the lowest intellectual behaviour and educational goals (Bloom and Krathwohl 1956). Therefore, not supporting application, analysis, synthesis and evaluation hinders students’ high level cognitive development and leaves students trapped in the first two levels of cognitive domains this taxonomy. That is, the inclusion of these concepts and their educational applications in the JCSS may support the progression of students’ cognitive thinking skills to higher levels because its inter-disciplinary perspective requires applying a context to other context (application level) and synthesising them together. Therefore, modifying the activities in an age appropriate way may support reducing the complexity of the topic and contribute to science education pedagogically.
Thirdly, PSTs were of the opinion that the inclusion of the contemporary social aspects of NOS and the components of the SAMI cycle framework in the JCSS could overload the curriculum due to their broad scope and limited teaching hours of science in schools. Furthermore, by referring to the assessment, PSTs addressed that teachers would not be willing to teach these concepts since they are not included in the curriculum and the national state exams. The dominant and centralised role of assessment in teaching and learning, in particular the impact of the Leaving Certificate examination\(^{26}\) on students and teachers in Ireland, is also addressed in the literature (e.g. Jeffers 2011). Assessment, being the “tail that wags the curriculum dog” (Hargreaves 1989, cited in Barnes et al. 2000, p.624), can influence both teaching approaches and content selection. According to Lange and Meaney (2012), “assessment, especially high stakes assessment, becomes the de facto curriculum for teachers”. Eisner (2004) adds to this by arguing that assessment and exam results are what count in schooling, therefore “what is tested is what is taught……students find ways to cut corners – as some teachers do” (Eisner 2004, p.300). Within this context (both international and national), PSTs views and concerns regarding including concepts that are not assessed may not seem surprising. Therefore, it can be anticipated that unless these concepts form part of the national assessment, it is unlikely that teachers will be willing to teach them in the classrooms due to the domination of “covering” the curriculum and fulfilling the assessment requirements.

7.2.3. Potential Inclusion of the Contemporary Social Aspects of NOS and the SAMI Cycle Framework for the JCSS

This section discusses potential inclusion of the contemporary social aspects of NOS and the SAMI cycle framework in the JCSS based on the PSTs’ views of the inclusion and the literature. The contemporary social aspects of NOS and the SAMI cycle framework were discussed within the social aspects of NOS and there is an element of NOS strand in the JCSS, namely “science in society”. Therefore, these concepts might be implied in “science in society” in the JCSS and weaved

\(^{26}\) Leaving Certificate examination is the final examination that students take at the end of their final year of second-level schooling, and it can determine their future study and career prospects.
throughout the JCSS in a holistic way. Additionally, the relevant understanding, knowledge, skills and attitudes of these concepts to science could be integrated in the JCSS.

When PSTs were asked about the inclusion of the contemporary social aspects of NOS and the SAMI cycle framework in the JCSS, the majority of participants supported this inclusion. Four themes emerged regarding the inclusion of these concepts in the JCSS, which are knowledge, skill, attitude and understanding. PSTs believed that each of these themes benefits students in different ways. For example, PSTs felt that improving students’ (1) understanding of economics/entrepreneurship and science can benefit students to make science more relatable to life, (2) knowledge of economics in science can benefit students to comprehend supply and demand between different concepts, such as economics and science, (3) economic and entrepreneurial skills can benefit students to manage their money successfully, and (4) entrepreneurial attitudes can encourage students to share ideas and convey the interest in science. While the knowledge was not mentioned much, understanding, skill and attitude were highlighted predominantly.

European Commission (2012) presented the integration of entrepreneurship into education within the categories of knowledge, skills and attitudes. Within this context, European Commission (2012) addressed that the knowledge of career opportunities and the world of work are some of the learning outcomes, which can benefit students in their future life.

Knowledge/understanding, skills and values/attitudes are also emphasised in the literature relating to the curriculum integration. For example, according to DES (2015):

> the importance of the processes of science as well as knowledge and understanding of concepts are reflected throughout the learning outcomes, which describe the understanding, skills and values that students should be able to demonstrate at the end of junior cycle.

(DES 2015, p.13)

Three of these themes, which are understanding, skills and attitudes/values were also mentioned in the JCSS with the reference to the aspects of EOS and
entrepreneurship. For example, in the JCSS within the SOL, the importance of improving economic understanding is referred by stating that “the student understands the origins and impacts of social, economic, and environmental aspects of the world around her/him” (DES 2015, p.6). Concerning skills, creativity - which is one of the features of entrepreneurship (Hisrich and Peters 2002) - is mentioned in the JCSS within the eight key skills in the JCSS involving “imagining”, “exploring options and alternatives”, “implementing ideas and taking action”, “learning creatively” and “stimulating creativity using digital technology” (DES 2015, p.7) as well as being targeted key skills of Ireland by 2025 (DES 2016). In this strategy plan of Ireland, particular emphasis was placed on that students at all stages of education and training will be educated with “ICT skills, language proficiency and entrepreneurship in the light of their importance to employability, personal development and civic participation” (DES 2016, p.73). The JCSS emphasise the importance of providing opportunities for students “to develop their abilities and talents in the areas of creativity, innovation and enterprise” (DES 2015, p.3).

Regarding the attitudes/values, the Junior Cycle aims to develop students’ “competence and confidence to meet the opportunities and challenges of senior cycle sciences, employment, further education and life” and making “them more self-aware as learners and become competent and confident in their ability to use and apply science in their everyday lives” (DES 2015, pp.4-5). These aims are also targeted in entrepreneurship education (Deveci and Seikkula-Leino 2016). Although students’ future career is important, this is not reflected in the curriculum. Therefore, inclusion of the career prospect in the curriculum can be suggested as a result of the current study.

If students are expected to learn the contributions of scientists in science and their impact on society and appreciate “the role of science in society; and its personal, social and global importance; and how society influences scientific research” (DES 2015, pp.6-11-17) the SAMI cycle framework and the contemporary social aspects of NOS may be the visual tool to be used within this aim (Kaya et al. 2018b). Therefore, the integration of the contemporary social aspect of NOS and the SAMI cycle framework in the JCSS are discussed within the themes of understanding, knowledge, skills and values/attitudes, and these themes are suggested to consider
if these concepts are to be integrated in the curriculum. In the next section, the implications of the pre-service teacher education are discussed.

7.2. PRE-SERVICE TEACHER EDUCATION

It is supported to include the contemporary social aspects of NOS (i.e. EOS and entrepreneurship) and the SAMI cycle framework in science education due to their perceived benefits by PSTs and potential contribution discussed in the literature. However, if these concepts (the contemporary social aspects of NOS and the SAMI cycle framework) are to be implemented in the JCSS, teachers should have an understanding of them and be able to apply them in the classroom. Furthermore, exploration of these concepts is an uncharted territory. Therefore, improving teachers’ and pre-service teachers’ understanding through in-service training or pre-service teacher education programmes is significant. Since the focus of the current study is the pre-service science teachers, implications for pre-service teacher education and science education are discussed in this section.

7.3.1. Implications for Pre-Service Teacher Education

Two teacher education approaches were applied in the current study; the continuous PSTE and the once-off PSTE. The current study found that there were changes in PSTs’ understanding of the concepts in both approaches and PSTs identified benefits of both approaches. Nonetheless, two PSTs, who were exposed to both continuous PSTE and once-off PSTE, felt that they learned more in the continuous PSTE than once-off PSTE. Additionally, the PST, who was only involved in the once-off PSTE, felt that even though the role-play activity was interesting and engaging, the continuous involvement would be more beneficial. The literature also articulated the effectiveness of the continuous involvement (Broggy et al. 2015; Garet et al. 2001; Mayock et al. 2007; McCormack 2010; Opfer and Pedder 2010). For example, Opfer and Pedder (2010) believes that continuous professional development leads to desirable changes in pupils’ teachers’ and school practices. According to Garet et al. (2001), there is a need for a continuous and intensive approach to teacher development, where teachers are exposed to topic-related different experiences over an extended period. Aligned
with this, the OECD (2009) defines the effective professional development of teachers as an ongoing process, which provides adequate time and follow-up support. These studies were emphasising that being exposed to topic-related different experiences over an extended period enhances pupils’, teachers’ or school practice.

However, there are some other studies indicating the effectiveness of both continuous and once-off involvement. For example, Broggy et al. (2015) found that even though both continuous and once-off involvement were beneficial to PSTs, PSTs who were involved in the continuous teacher development showed a more effective change. The current study also found similar findings to Broggy et al. (2015). Even though PSTs addressed benefits of both approaches and their understanding changed in both approaches, PSTs found the continuous PSTE more effective than the once-off PSTE. The effective professional development requires the continuous engagement in a programme over a number of weeks.

However, PSTE is busy with various different topics needing to be explored. This may prevent teacher educators from exploring certain concepts over an extended period of time. This shows that even though the continuous exposure to the topic is more effective, one time exposure might be required in teacher education due to the overloaded teacher education programmes. One possible solution might be for teacher education programmes to adopt a spiral curriculum approach (Bruner 1960) allowing these concepts (i.e. the contemporary social aspects of NOS and the SAMI cycle framework) to be taught.

A spiral curriculum approach supports the teaching of complex ideas at a simplified level first, with these simplified ideas being revisited at a more complex level later on (Bruner 1960). There are many studies supporting the use of spiral approach. For example, Eriksson et al. (2014) adopted the spiral approach in their teaching and found that students’ disciplinary knowledge increased through the process of learning by crossing a category boundary and moving to the next level of the anatomy of disciplinary discernment for each turn in the spiral. In this sense, the once-off PSTE could be applied by providing all of the concepts at a basic level once each year of the teacher education programme. These concepts could then be revisited at a more complex level in the following years, which provide the
continuous PSTE. Once these once-off and continuous PSTE approaches are intertwined in a spiral curriculum approach, the efficiency of teacher education programmes might be increased and the issue of the programmes being packed might be eased.

How the spiral curriculum could be applied in teacher education is exemplified here. For example, if one was to teach the electric circuit analysis in the first year of the programme, while PSTs are learning electric circuit analysis, they can learn that Edison took this idea and converted it into a product (lamp) and he is an entrepreneurial scientist. Then, in the second year, they can learn the features of entrepreneurs and features of scientists, and combine and discuss the features of entrepreneurial scientists. In the third year, they can learn that there are different ways of creating entrepreneurial scientists, such as incubator programmes, which are also applied by some scientists, such as Edison and some universities, such as the Massachusetts Institute of Technology (MIT). In the fourth year, they can conduct a project to start a business based on a scientific idea/product. This example illustrates that a concept could be taught at different stages by gradually increasing its complexity. Applying a spiral curriculum might solve the issue about time limitation to teach a topic; however, it could also remove the concerns regarding the ineffectiveness of being exposed to a topic only once by providing the longer exposure throughout four years. Additionally, integrating and interweaving EOS, entrepreneurship and the SAMI cycle framework might eliminate some of the concerns regarding the busy schedule of PSTE programmes and could also reduce PSTs’ fragmented understanding of knowledge.

The current study applied the once-off PSTE and continuous PSTE separately in a small group in one university. Future studies could explore the impact of a continuous approach, the once-off approach and spiral curriculum approach to teaching such concepts. The results could be compared, and a more informed decision could then be made on the most effective approach for teacher education.

7.3.2. Implications for Science Education

There are different implications of the contemporary social aspects of NOS and the SAMI cycle framework for science education. Teacher education could incorporate
these through different pedagogical activities, such as the story-based group discussion, the concept statement, the crisis management and the role-play activities. These approaches and their implications are discussed in the following paragraphs. Even though all approaches were targeting the contemporary social aspects of NOS and the SAMI cycle framework, each approach did not focus on all dimensions but rather focused on one or two concepts, as described below. This exploration of the potential implications would be beneficial for science education since this is an uncharted territory as mentioned previously.

The story-based group discussion activity was designed to focus on the relationship between academia, market and industry and the definition of the SIS of science. The historical science stories are important in NOS teaching (Allchin 2011; Allchin et al. 2014). Furthermore, the group discussion is an effective teaching method in science education (Alexopoulou and Driver 1996). The data showed that PSTs felt that they learned about science as a social-institutional system. Furthermore, they mainly emphasised the interdisciplinary links that science has, which refers to the link between science and different concepts, such as industry and government. It was suggested that the story-based group discussion might make students consider other people’s perspectives more. The story-based group discussion could be implemented in science education to improve students’ understanding of the SIS of science and the interdisciplinary links that science has. The importance of which is referred in the JCSS (DES 2015). Furthermore, PSTs’ ability to work in groups might be improved by implementing this activity in teaching. The improvement of this ability is important since “working with others” is one of the key skills in the JCSS and teachers need to implement these skills in their classes (DES 2015).

The concept statement activity was designed to focus on entrepreneurship and EOS in NOS. A business plan is an effective way to improve someone’s understanding of entrepreneurship (Etzkowitz 2008). Furthermore, the concept statement activity could play a role as a project assignment for different science subjects (Kaya et al. 2018b). Literature also showed that entrepreneurial thinking and science process skills could be improved by producing innovative science based products (Buang et al. 2009). Similarly, in the current study, the results from the concept statement activity showed that participants were able to integrate entrepreneurship in their innovative science based products. PSTs felt that they learned about exploring
options and alternatives when they need to find a solution to an issue, which is relevant to “being creative” in the eight key skills of the JCSS (DES 2015). PSTs felt that they learned about other people’s perspectives and the interdisciplinary links and had better understanding of entrepreneurship and economics and making links between science, entrepreneurship and economics due to working with others in a group on the concept statement activity during over a month. The concept statement activity could be implemented in science education to improve students’ understanding of EOS and entrepreneurship in NOS and therefore the interdisciplinary links that science has. The importance of which has been discussed when presenting the story-based group discussion. It was suggested to meet an actual company manager or relevant business people to talk about their business idea to make this activity more beneficial and effective. Therefore, future studies might brought actual company managers or relevant business people and PSTs to talk about their business idea.

The crisis management activity was primarily designed to focus on entrepreneurship and EOS in NOS. Specific goals were to increase participants’ awareness of potential risks and support them to find possible solutions for these risks before they turn into a crisis. In this sense, this activity was supporting the development of different skills, such as risk taking, problem solving, critical thinking and decision making. The crisis management can be used in scientific disciplines as well as business subjects (Pearson and Claire 1998; Ritchie 2004), this activity might be applied to improve these skills in science classes since the participants expressed that they learned about exploring different solutions by trying different approaches to solve an issue and making considered decisions throughout this activity. PSTs felt that they started to think from different people’s perspectives and learned about working with others. “Working with others” is one of the key skills in the JCSS (DES 2015).

Furthermore, PSTs were of the opinion that they were able to make considered decisions by listening to different perspectives, which is referred in “managing myself” in the eight key skills of the JCSS (DES 2015). PSTs felt that they learned about the interdisciplinary links and had better understanding of the links between science and economics through collaborative discussions, such as the role of funding in science. Participants also perceived that they learned about exploring
different solutions by trying different approaches to solve an issue. “Exploring options and alternatives” is presented within “being creative” in the eight key skills in the JCSS (DES 2015). Additionally, it was suggested that the crisis was very good to identify the hurdles in the concept statement. It was recommended to spend more time to explain and explore the possible solutions to the crisis in the crisis management activity. Therefore, further research can be conducted on improving the mentioned skills through crisis management activity by providing longer time for the activity. Due to the relevance of the concept statement activity to the crisis management activity, it is suggested to use these activities together.

The role-play activity was primarily designed to focus on the SAMI cycle framework as well as referring to the social aspects of NOS. The role-play is an educational teaching strategy (Cohen et al. 2011). Furthermore, PSTs should know about some of the rationales and key skills referred in this activity because they are already involved in the JCSS. For example, PSTs were of the opinion that the role-play activity was engaging due to being more active and interesting, using their imagination and thinking about the next steps. While “imagining” is one of the eight key skills in the JCSS, interest and engagement in science is one of the rationale of science in junior cycle (DES 2015). PSTs felt that even though there were similarities between the story-based group discussion and the role-play activity, they found the role-play activity more engaging and involving. Moreover, they perceived that in the role-play activity, they learned more about the interrelations between the components of the SAMI cycle framework as well as improving slight understanding of the role of EOS and entrepreneurship in how science works in society. They also felt that the role-play activity made them think about how science works. Developing an understanding of how science works is the aim of NOS (Erduran and Dagher 2014a; Irzik and Nola 2014) and NOS is the framework of the JCSS (DES 2015). The role-play activity could be implemented in science education to improve students’ understanding of this framework while conceptualising EOS and entrepreneurship, and therefore the interdisciplinary links that science has. Furthermore, PSTs’ ability to work in groups could be improved by implementing this activity in teaching. It was recommended by participants to assign a facilitator/guide for each small group. Assigning an instructor to each group might be one of the suggestions for future studies.
Overall, the results are aligned with the literature indicated that these activities could benefit and could be applied in science education. PSTs were of the opinion that these activities made them think and therefore they started to acknowledge different aspects and perspectives in science and the relationship between different stakeholders related science. It was suggested that these activities made them realise the bigger picture of science, which involves how science and scientists work outside of the scientists’ workplace. This may be interpreted as how science works in society. Deveci and Seikkula-Leino (2016) found in Finland that classroom activities were highly preferred by teachers. Likewise, in the current study, PSTs preferred classroom activities such as role-play, concept statement and project development. According to the OECD (2009), an effective teacher education programme involves teachers in learning activities that are similar to ones they will use with their students. Since these activities have references to the JCSS, they might be useful and effective science teaching approaches for PSTE. However, further research is required to apply with a bigger sample size to prove their effectiveness.
CHAPTER EIGHT: CONCLUSION

This study aimed to develop and explore PSTs’ understanding of the role of EOS and entrepreneurship in NOS and the SAMI cycle framework. The place of EOS and entrepreneurship within the social aspects of NOS were investigated, and a new framework illustrating how science works in society, the SAMI cycle framework, was proposed. Therefore, this study contributes to science education by proposing the inclusion of the contemporary social aspects of NOS (i.e. EOS and entrepreneurship) and the SAMI cycle framework. According to the data and the literature, the inclusion of these concepts may contribute:

1. To improve students’ EOS and entrepreneurship related knowledge/understanding, skills and attitudes/values in science classes, which may be required when they are starting a job in future.
2. To contribute to the social and economic development of a country.
3. To improve students’ understanding of the world, how science works in society and the role of science in everyday life, which are involved in the aims of science education.
4. To support the interdisciplinary relationships that science has.
5. To make students realise the bigger picture of science.
6. To motivate students and increase their interest in science.
7. The holistic understanding of science.

This study also contributes to science education through the development of a variety of teaching resources (i.e. science education approaches), such as the concept statement activity, which were developed for the current study. These concepts (i.e. EOS, Entrepreneurship and the SAMI cycle framework) were then integrated into the continuous PSTE and the once-off PSTE. Therefore, the current study explored PSTs’ understanding of these concepts before and after this programme and their educational views of integrating these concepts into the JCSS. Furthermore, the inclusion of the contemporary social aspects of NOS and the
SAMI cycle framework in the JCSS and the possible implications for teacher education were discussed. The current study is concluded based on the research questions, future directions are proposed, and a personal reflection is presented in this chapter.

8.1. CHANGES IN PSTS’ UNDERSTANDING OF THE CONTEMPORARY SOCIAL ASPECTS OF NOS

The reason for looking for the changes in PSTs’ understanding of the contemporary social aspects of NOS was (1) the importance of EOS and entrepreneurship in NOS and science education and (2) the role of teacher education in the implementation of these concepts, which were articulated in the first three chapters. Within this context, EOS and entrepreneurship were explored, and entrepreneurship was re-defined in the context of NOS. The inclusion of the “contemporary social aspects of NOS” in NOS and science education was proposed to promote a holistic and comprehensive understanding of NOS.

It was advanced and argued in the literature review of the current study (Chapter Two and Chapter Three) that EOS and entrepreneurship in NOS should be included as dimensions of the contemporary social aspects of NOS. When advancing this argument, the importance of EOS and entrepreneurship in the science education literature were stressed. For example, it has been argued that a rudimentary form of EOS is already in the NOS literature (See Section 2.1), and entrepreneurship is not explicitly addressed (See Section 2.3) but referred to in NOS by emphasising science as an enterprise (Erduran and Dagher 2014a; Irzik and Nola 2011, 2014). Thus, these aspects were categorised as the contemporary social aspects of NOS within the social-institutional system of science. However, the contemporary social aspects of NOS can change according to the needs of the global world.

Even though PSTs did not have a deep understanding of the contemporary social aspects of NOS at the beginning of the current study, there were improvements in their understanding of the concept at the end of both the continuous PSTE and
once-off PSTE. The differences in their understanding were determined from the thematic analysis, network analysis and Wilcoxon signed-rank test results. In both before and after the current study, PSTs portrayed a fragmented understanding of what is involved in science, what science requires and what scientists do. For example, they appear to think that scientists can only do a particular type of work, and scientists and entrepreneurs as entities cannot be combined. However, the fragmented understanding was less evident after the interventions. It was proposed that the inclusion of the contemporary social aspects of NOS by adopting a spiral curriculum approach (Bruner 1960) might be a good start for developing a holistic understanding.

PSTs perceived many benefits to the inclusion of these concepts in NOS and the JCSS. PSTs mentioned the benefits of these concepts as relating to the economic development of a country as well as its broader benefits to students and the society. For example, including such concepts may increase students’ awareness of a variety of job opportunities and provide equal opportunities to all students. Increasing students’ awareness on the job opportunities and economics-related issues through embracing the contemporary social aspects of NOS (Achor and Wilfred-Bonse 2013; Deveci 2016) supports to create industry-ready graduates to satisfy the need in the global world (Hynes et al. 2010) and improves the “social wealth” in a country (Venkataraman 1997). As a result, this contributes to the social and economic development of a country (Amos and Onifade 2013). The countries need scientifically literate responsible citizens who are concerned with their role in the social and economic development of their country (Kelly 2007), and this might be achieved by the inclusion of the contemporary social aspects of NOS. Furthermore, students will be able to make informed decisions about many of the local, national and global challenges and opportunities (DES 2015).

8.2. CHANGES IN PSTS’ UNDERSTANDING OF THE SAMI CYCLE FRAMEWORK

The reason for looking for the changes in PSTs’ understanding of the SAMI cycle framework was the same with the contemporary social aspects of NOS. NOS aims to understand how science works (Erduran and Dagher 2014; Irzik and Nola 2014),
and therefore, the question of how science works in society was asked and answered by utilising the SIS of NOS. Based on the elements emerging from EOS, entrepreneurship and the SIS of NOS (i.e. state/government, academia, market and industry), the SAMI cycle framework was developed to illustrate how science works in society by explaining the relationship between state/government, academia, market and industry. This framework aims to promote a holistic and comprehensive understanding of NOS.

It was advanced and argued in the literature review of the current study (Chapter Two and Chapter Three) that the SAMI cycle framework conceptualises EOS, entrepreneurship and the elements of the SIS of NOS to explain how science works in society. When advancing this argument, the phases of how EOS, entrepreneurship and NOS engender the SAMI cycle framework were presented (Kaya et al. 2018b). Therefore, PSTs’ references to the components of the SAMI cycle framework when discussing EOS and entrepreneurship can be a precursor of PSTs’ understanding that the SAMI cycle framework is the conceptualisation of EOS and entrepreneurship.

Even though PSTs did not have a deep understanding of the SAMI cycle framework at the beginning of the current study, as was to be expected, there were improvements in their understanding of the concept at the end of both continuous PSTE and once-off PSTE. As before, this was evident in their thematic analysis, network analysis and Wilcoxon signed-rank test results. The same issue regarding a fragmented understanding of what is involved in science and what science requires also emerged regarding the SAMI cycle framework. For example, PSTs appeared to think that scientists can only do a particular type of work, and there are only dual relationships between academia and the other components of the SAMI cycle framework. However, the data showed that PSTs’ holistic understanding of science slightly increased following engagement in the current study. Holistic understanding of a concept or a subject is desired (Erduran and Dagher 2014a) and might be enhanced by the inclusion of the SAMI cycle framework and adopting a spiral curriculum approach (Bruner 1960).

PSTs perceived many economic and social benefits of this inclusion in science education and the JCSS, such as increasing students’ motivation, interest and
confidence in science and increasing students’ understanding of the world and society. Furthermore, in the literature, the contributions of the SAMI cycle framework to science education were justified in terms of improving the second or third-level students’ and teachers’ understanding holistically and contributing the economy and society (Kaya et al. 2018b). Increasing students’ awareness on the social aspects of NOS in science classes may contribute to students’ knowledge and skills (Kaya and Erduran 2016), such as improving their communicating skills and their management of information and thinking skills. Therefore, students can make considered decisions as well as realising that scientists benefit society more by conducting scientific research. Performing this integration contributes to “the improvement in the students’ interpretation of the relationship between science and society” (Kaya et al. 2018b, p.475). Furthermore, this framework might provide many benefits of the contemporary social aspects of NOS since this framework is the conceptualisation of EOS, entrepreneurship and NOS. The SAMI cycle framework should support more authentic and engaging science classes.

8.3. PSTS’ VIEWS ON THE INCLUSION OF THE CONTEMPORARY SOCIAL ASPECTS OF NOS AND THE SAMI CYCLE FRAMEWORK IN THE JCSS

The reason for looking at PSTs’ views on the inclusion of the contemporary social aspects of NOS and the SAMI cycle framework in the JCSS was that if they are important and beneficial to NOS and science education, it is important to learn about PSTs’ perspectives to predict if they are applicable in science education. Furthermore, PSTs’ views of the inclusion of these concepts in the JCSS is important because it may be difficult to change what PSTs know once they start teaching at schools. Therefore, based on PSTs’ views of the inclusion of these concepts, suggestions were made on how they could be implemented in the JCSS and possible implications for science education.

The majority of PSTs supported the inclusion of the contemporary social aspects of NOS and the SAMI cycle framework in the JCSS because of the possible
benefits to students and science education. Understanding, knowledge, skills and attitudes emerged as themes as a result of thematic analysis of PSTs’ views in Chapter Five. Moreover, these themes are also emphasised in the literature relating to curriculum integration. For example, DES (2015) highlighted the knowledge, understanding, skills and values, which need to be improved in science education, and European Commission (2012) presented the integration of entrepreneurship into education within the categories of knowledge, skills and attitudes. Therefore, it was proposed that if the contemporary social aspects of NOS and the SAMI cycle framework are to be included in the JCSS, they could be integrated in the JCSS within the social aspects of the NOS (i.e. “science in society” element in NOS strand in the JCSS) and weaved throughout the specification as knowledge, understanding, skills and attitudes.

The participants raised some concerns, namely the current inclusion of these concepts within the different subjects at different levels in the curriculum, their suitability to the age of junior cycle students and not being part of the assessment. The concern regarding the current inclusion was explained that these concepts might be included in the junior cycle and senior cycle, but they are involved in a fragmented way, separated from science. The current study proposed their inclusion in science in a holistic manner. The concern relating to providing concepts above their level was discussed based on their current existence in the junior cycle curriculum. The concerns regarding PSTs’ understanding of the assessment shaping what needs to be taught in the classroom and what needs to be included in the curriculum remained problematic, although not unexpected. Assessment, particularly high stakes assessment can influence both teaching approaches and content selection (Lange and Meaney 2012) and influences what teachers, and students, do in the classroom. Therefore, it can be anticipated that unless these concepts form part of the national assessment, it is unlikely that teachers will be willing to teach them in the classrooms due to the domination of the pressure of catching up with the curriculum and fulfilling the assessment requirements.
8.4. IMPLICATIONS FOR SCIENCE EDUCATION AND TEACHER EDUCATION

Even though many studies support the effectiveness of continuous involvement (Broggy et al. 2015; Garet et al. 2001; Mayock et al. 2007; McCormack 2010; Opfer and Pedder 2010), as in the current study, this is not always feasible. Therefore, one solution may be to adopt a spiral curriculum approach (Bruner 1960) enabling concepts to be introduced at the start of a programme and revisited in a more in-depth and higher order level as the students progress through the programme. In this sense, the once-off PSTE could be applied by providing all of the concepts at a basic level once each year. These concepts could be revisited at a more complex level in the following years, which provide the continuous PSTE.

Additionally, science education activities developed here may be beneficial in PSTE. For example, the story-based group discussion could be implemented in science education to improve students’ understanding of the SIS of science and the interdisciplinary links that science has. The concept statement activity could be implemented to improve students’ understanding of EOS and entrepreneurship in NOS and therefore the interdisciplinary links that science has. The crisis management activity might be applied to improve students’ analytical thinking skills in science classes and make student considered decisions. The role-play activity could be implemented to improve students’ understanding of the SAMI cycle framework while conceptualising EOS and entrepreneurship, and therefore the interdisciplinary links that science has. PSTs found the role-play activity the most engaging between these science education approaches. Furthermore, PSTs’ ability to working in groups could be improved by implementing these activities in teaching.

8.5. FUTURE DIRECTIONS

Technology was identified as a theme in the current study, and there is evidence of the relevance of technology to science, EOS and government in the literature (Mirowski and Sent 2008; Pedretti and Nazir 2011). In the future studies, the role
of technology in the social aspects of NOS can be explored within the contemporary social aspects of NOS or as one of the scopes of EOS. Furthermore, technology could be added to the SAMI cycle framework. Technology can be integrated as a tool or as a concept based on the relevant literature. While knowledge, products or services are transferred from academia to market, technology transfer offices play a role during the process. These offices also support the transfer of technologies from academia to the private sector through the industry and educate faculty members in the utilisation of their research (Etzkowitz 2008; Van Norman and Eisenkot 2017a, 2017b). When a university is successful at technology transfer, this university has more opportunities for providing more funding and exchanging required materials, information and personnel with private industry (Van Norman and Eisenkot 2017a, 2017b). This improves research opportunities for their faculty members and students. Based on the above explanation, one way of integrating technology, for example, is accepting it as a tool in the process of the transferring the knowledge and products from academia and industry to the market. Therefore, technology could be integrated between academia, industry and market in the SAMI cycle framework. Additionally, engineering is also related to science and entrepreneurship (Purzer et al. 2016). Therefore, the SAMI cycle framework can be developed further to utilise STEM education and engineering education. Thus, the relevance of technology to the contemporary social aspects of NOS and the SAMI cycle framework could be developed further.

Future studies could also investigate the implications of the contemporary social aspects of NOS and the SAMI cycle framework for primary and second level education by developing some activities or adapting the activities used in the current study in an age-appropriate way. Additionally, even though contributing the students’ future life is significant in an education system, the support for students’ career choice is limited in the curriculum. Therefore, the inclusion of the career prospect in the curriculum can also be suggested as a result of the current study.

Concerning the implications for teacher education, the changes in PSTs’ fragmented understanding of science due to the inclusion of the contemporary social aspects of NOS and the SAMI cycle framework seem hopeful. The results
indicated that emanation of a holistic understanding could take some time and require continuous practice in a subject area, but it can be achievable. It is suggested to investigate the spiral curriculum approach by teaching the concepts at a basic level once in each year in the once-off PSTE, and revisiting these concepts at a more complex level in the following years. Adopting the best of both approaches (once-off and continuous) in a spiral curriculum approach may increase the efficiency of teacher education programmes. The current study applied the once-off PSTE and continuous PSTE separately in a small group in one university. Future studies can apply the continuous PSTE, the once-off PSTE and spiral curriculum approach with a more representative sample. The results could be compared, and a more informed decision can be made on the most effective approach for teacher education.

8.6. PERSONAL REFLECTION

To conclude, I will briefly reflect on how the current study emerged, and how my views on the research project have evolved during the study. Furthermore, I reflect on what I would do differently if I were to conduct the current study again.

When I heard the term “entrepreneurship” in education for the first time, I was surprised how entrepreneurship and education are relevant. I started to research “entrepreneurship” since it was one of the key skills in my country of birth, Turkey. As I researched more, I started to realise its connection with EOS and their possible benefits to science education more. In the meanwhile, while I was attending to a reading group and discussing the elements of NOS, in particular, the extended FRA for NOS, I started to realise the relationships between the aspects of the social-institutional system of science, EOS and entrepreneurship. I believed that even though EOS and entrepreneurship are perceived by many people as only beneficial for economic development, they might benefit science education when it is investigated and applied in a broader context. I did not follow any political view or ideology; I only wished to contribute to science education.

I initially designed the current study for the continuous involvement of a small group of PSTs. However, when I had a chance to apply the current study with a
bigger group, I pursued this opportunity by willing to make more significant contribution to teacher education. As I was immersed in this research experience and observed the changes in participants’ views, I started realising the possible benefits and concerns of the current study. As I investigated the participants’ views more, I found how their views are relevant to the curriculum and assessment. I am now aware that the assessment is majorly dominating the curriculum related decisions. In other words, assessment is “tail that wags the curriculum dog” (Hargreaves 1989, cited in Barnes et al. 2000, p.624).

During the role-play activity in the once-off PSTE, I was also challenged due to not having an instructor assigned to each group and having limited time to apply the concepts. If I were to complete the current study again, I would look for some instructors for help. Furthermore, I would try to recruit a bigger group for a longitudinal study. If sufficient funding was available, I would advance the current study by bringing over actual company managers or relevant business people to engage with the PSTs, as suggested by PSTs in the current study.

Having completed the current study and acknowledged all aspects of the arguments made, I believe that EOS and entrepreneurship, and maybe some other fields (e.g. technology), are a part of the contemporary culture and they have an impact on how science works in society. I feel that science does not only work in academia but also in society, and there are the other concepts that contribute to the development of science and its transition between the fields to utilise society. Therefore, I plan to use these ideas in my professional practice. For example, I can develop concept statements with students when teaching science, mention the “entrepreneurial scientists” and their achievements in the classroom or bring an academic to the classroom who is currently working for a company. My future goal is to carry the SAMI cycle framework a step further by the inclusion of technology and engineering and conduct research on entrepreneurship in STEM education by utilising the extended SAMI cycle framework.
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APPENDICES

APPENDIX 1: The Education System in Ireland

APPENDIX 2: Science as a Social Institutional System
APPENDIX 3: Science as a Social Institutional System After the Suggested Changes
APPENDIX 4: Pre-interview Questions

This research has received ethical approval from the Faculty of Education and Health Sciences Research Ethics Committee University of Limerick, Approval Number 2016_03_03_EHS

PRE-INTERVIEW

The purpose of the interview is to elicit the participants’ perceptions of “science as a social-institutional system”. For this goal, 17 main interview questions and some sub-questions are posed to each participant of the study. One of the questions is the diagram construction to explain the operation of science and the rest of the interview includes answering the following questions verbally. The total interview time is about 40-50 minutes for each participant.

1. Is science related to society? Using examples please expand your answer.
2. What do you think about the meaning of the social system?
   2.1. Do you think science is a social system? Please explain your answer.
3. What do you think about the meaning of the institutional system?
   3.1. Do you think science is an institutional system? Please explain your answer.

If the participant is of the opinion that science is a social-institutional system, the interviewer will continue with the questions (3 and 4) below:

4. By using the words provided can you construct a diagram to explain how science works in society? (Give a paper sheet, words, blue tag, post-its). You can add or remove some of the words to construct your diagram.
   4.1. How do you see the relationships and connections between these words?

If the participant is not of the opinion that science is a social-institutional system, the interviewer will continue with the questions (3 and 4) below:

4. By using the words provided can you construct a diagram to explain how science works? (Give a paper sheet, words, blue tag, post-its). You can add or remove some of the words to construct your diagram.
   4.1. How do you see the relationships and connections between these words?
5. Which social or scientific organisations can scientists work for?

6. Do you think scientists do some other activities other than conducting research?
   6.1. What are the kinds of professional activities scientists do?
   6.2. Do you think these activities are necessary? Why?

7. Do you think economics has an impact on actions of scientists? Using examples please explain your answer.
   7.1. What kind of impact does the inclusion of economics in science have?

8. Do you think external factors such as the market affect how science works? How?

9. Market means the place where the buyers and sellers interact to trade products and services to fill the supply and demand gap. How are the patents and knowledge transferred from the scientific fields to the market?

10. Where do you think market provide the required knowledge and patents?

11. Have you ever heard the term scientific enterprise previously? If so: in what context? What do you think it means?

12. What about entrepreneurship? What does it mean?

13. Do you think entrepreneurship has a place on how science works? Can you give an example?

14. What do you think about the inclusion of entrepreneurship in science classes to explain how science works?

14.1. Do you think entrepreneurship is applicable in science classes?

15. What do you think about improving entrepreneurial skills and attitudes in science classes?

15.1. Do you think it is necessary or not? Why?

I have no further questions. Do you have anything more you want to bring up, or ask about, before we finish the interview?
APPENDIX 5: Story-based Group Discussion

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- Read The Graphene Story And Complete The Activity Below Within Your Group.

THE STORY OF GRAPHENE

If you have ever drawn anything with a pencil, you have very likely made graphene. Graphene is fundamentally one single layer of graphite. Millions of ultra-thin graphene are accumulated to form graphite and usually found in pencils. Although graphene was pointed out theoretically in 1984, the name ‘graphene’ was first mentioned in 1987 to describe the graphite layers. Since then, many scientists used complex experiments to find graphene but, for the first time, it was discovered in 2004. Andre Geim and Konstantin Novoselov held ‘Friday night experiments’ sessions where they would conduct experimental research not directly linked to their day jobs. During Friday evening experiments in Manchester, two scientists removed some flakes from graphite with a scotch tape used to clean a graphite stone, and noticed small parts of graphene on the tape. Thereby, Geim and Novoselov had isolated graphene for the first time and were awarded with the Nobel Prize in Physics 2010 for this simple but ground-breaking experiment using a method namely ‘ordinary scotch tape’. Thanks to the scotch tape method, today hundreds of laboratories all over the world deal with different aspects of graphene research. Furthermore, the University of Manchester still holds the weekly Friday afternoon seminars tradition to share and discuss new research by the attendance of many graphene researchers.

What makes graphene a super material?

Graphene is;

1. the first two dimensional crystal
2. the thinnest material
3. the lightest material
4. the world’s strongest material, harder than diamond and about 300 times stronger than steel
5. a transparent material
6. bendable and formed into any shape
7. conducting electricity much better than copper
8. created a new class of crystals that can be shuffled with each other

The discovery of graphene revolutionised almost every part of daily life. On the grounds of all these features, different industries started to demand graphene or its derivatives to engineer new
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materials in order to meet the industries’ special needs and thereby graphene is moved to the graphene market place. The term was used extensively in work on carbon nanotubes. It has also applications in (1) producing membranes to clean the drinking water, (2) producing composites and coatings to prevent deterioration of ships and cars, or the food to go off, (3) storing and producing energy, (4) biomedical, (5) developing sensors to detect dangerous particles, and (6) electronics. Therefore, graphene research is making a substantial impact on a range of industries such as transport, medicine, electronics, energy, defence, desalination.

**ACTIVITY: Argumentation**

Social-institutional system of science includes individual scientists working in academic institutions such as universities, in scientific research centres or in industry. These individual scientists also affect and are affected by social values and activities. Consider the following competing claims about how science works.

**Claim 1: Science is a social-institutional system**

**Claim 2: Science is not a social-institutional system**

Follow the instructions below:

- a) Divide into two groups as each group will support one of the claims (*1 person will be working for the two groups*)
- b) Read the story of the graphene carefully
- c) Develop claim(s) and use the graphene story to build up support for your claim(s) (*10 min*)
- d) Make sure that you justify why you think the evidence that you choose in the graphene story support your claim
- e) Be careful about the evidence can be used by the other group to refute your claim
- f) Come together with the other group and conduct a discussion together (*20 min*)
- g) Define the components of how science works as a group
### Table 2: Example student activity aimed at secondary schooling to promote argumentation about discovery/invention and fact/artefact themes

**Student activity:** Oncomouse: To patent or not?

Consider the following competing claims about a genetically modified mouse that was produced at Harvard University. The oncomouse was designed to be susceptible to cancer and it is intended to help scientists understand cancer. In your groups, discuss each claim and use the evidence statements to build up support for your claims. Some of the evidence may be relevant for one claim or the other at the same time. Some evidence may be irrelevant and some may only be relevant for one claim. Make sure that you justify why you think that the evidence goes with your claim.

**Claim 1:** The oncomouse is a genetically modified animal that has been invented. It has to be patented with due financial rewards granted to its inventors.

**Claim 2:** The oncomouse belongs to all humanity and science; it cannot be patented to particular individuals.

**Evidence statements**

<table>
<thead>
<tr>
<th>Gene statement</th>
<th>Scientific statement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genes are made of DNA whether they are produced in the laboratory or exist naturally</td>
<td>Scientists deserve to patent the important discoveries and inventions they work hard at achieving</td>
</tr>
<tr>
<td>Science belongs to all humanity and help cure diseases</td>
<td>Modified genes are not the same as naturally existing genes</td>
</tr>
<tr>
<td>The mice and human beings are very different genetically. There is no use in researching cancer in mice to help humans</td>
<td>All governments should have policies to control scientists and what they do</td>
</tr>
<tr>
<td>An invention is something that does not occur naturally</td>
<td>All citizens in a democratic country have the right to own property</td>
</tr>
<tr>
<td>Patents are for commerce, not for science</td>
<td>Everything comes with a price in life</td>
</tr>
<tr>
<td>Genetically modified genes that cause cancer are not the same as naturally existing genes that cause cancer</td>
<td>Scientists are human beings who have to survive and need money to live</td>
</tr>
<tr>
<td>The oncomouse may have modified genes but it is still an animal</td>
<td>Modified genes are discoveries about how genes can behave in different circumstances</td>
</tr>
<tr>
<td>Cancer is a disease with a market</td>
<td>There is great demand for the treatment of cancer</td>
</tr>
<tr>
<td>The oncomouse will help us become more productive in dealing with human fatality due to cancer</td>
<td>It is unrealistic to expect that science is free from commercialisation in this day and age</td>
</tr>
<tr>
<td>If you want to be treated of cancer, you need to pay for it</td>
<td>If we patent the oncomouse, this will help scientists to be competitive in the market and produce better discoveries</td>
</tr>
</tbody>
</table>

### Table 3: Key concepts to complement the oncomouse activity

**Key concepts**

<table>
<thead>
<tr>
<th>Market concepts</th>
<th>Commercialisation</th>
<th>Demand</th>
<th>Commodity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Markets: are the systems, institutions, procedures and social relations by which people exchange goods</td>
<td>is the process of introducing a new product or process into the market</td>
<td>is the desire to own something and pay for it</td>
<td>is an item that can be produced to satisfy the needs and wants of a market</td>
</tr>
<tr>
<td>Supply: is the amount of product that is available to customers</td>
<td>Growth: is increase in quantity over time</td>
<td>Productivity: is a measure of the efficiency of production. It is a ratio of production output to input</td>
<td></td>
</tr>
</tbody>
</table>

Source: Erduran and Mugaloglu (2013)
APPENDIX 7: Concept Statement Activity

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PREPARING CONCEPT STATEMENT:

This part of the study aims to provide you a more informed insight into scientific enterprise. Concept statement is an overview of new product or service proposal. As a team, you are expected to come up with a business idea related to science. You will develop a 3 page concept statement outlining the proposal of your product or service business idea by taking into account the market demand for your product/service offering. You have one month to complete this part of the research. This document should include:

1. Overview of and rationale for the proposed business idea (including scientific background)
2. Description of the concept (characteristics, attributes etc)
3. Advantages and disadvantages of the proposed idea
4. Estimated budget calculation
5. Brief outline of the targeted buyers and and their possible reaction to the offering (who will buy this and why)
6. A description of how the product or service will be sold

Think about:

1. Scientific knowledge behind this idea
2. Patenting
3. The market
4. Industry

Background knowledge:

The concept statement used here is an overview of a business model describes the rationale of how a firm creates, delivers, and captures customer value to generate profits. You can review the Business Canvas Model to develop your business idea.
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The Business Canvas Model allows the entrepreneur to describe and think through the business model of a firm. A number of key areas in the model are interlinked. These areas influence each other while the business is moving from concept to commercialisation. Basically you can focus on four key components of the model: customers, offer (product/service), infrastructure, and financial viability.

**Key definitions:**

**Market:** Market means the place where the buyers and sellers interact to trade products and services to fill the supply and demand gap.

**Industry:** An industry is a group of manufacturers or businesses that produce a particular kind of goods or services.

**Entrepreneur:** A person who organises, operates, and assumes the risk for a business venture.

**Scientific enterprise:** Scientific enterprise refers to science-based projects developed by, or in cooperation with, private entrepreneurs.

**Commercialisation:** The process of making a new product obtainable in the market is commercialization. Commercialization of science allows funders to make profits through research projects whilst this increases the funding opportunities of scientists to conduct their research project.
APPENDIX 8: Focus Group Discussion Instruction Sheet

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FOCUS GROUP DISCUSSION

Follow the instructions below:

1. Come together as a group (n=3) and explain your business idea
2. Conduct a discussion on your concept statement. Discuss why your current business idea is better or more applicable than your other ideas; the issues which can arise on the application of this idea into practice; how these issues can be sorted; and the advantages and disadvantages of the commercialisation of science in the way you did.
3. You can conduct your discussion based on the questions below and ask further questions if needed.
   - *What is your business idea?*
   - *How did you come up with this idea?*
   - *What other business ideas did you have?*
   - *Why did you choose this idea instead of your other ones?*
   - *What did you do afterwards?*
   - *How did you share the duties?*
   - *How do you plan to apply your business idea? Give some details.*
   - *Have you thought about the possible issues? What are the challenges to put this idea into practice?*
   - *What have you done to overcome these issues?*
   - *What are the benefits of commercialising this scientific knowledge, patent, etc.?*
   - *What are the drawbacks of commercialising this scientific knowledge, patent, etc.?*
   - *What did you learn from this part of the study?*

During the discussion, (1) justify the rationales of your business idea, (2) build up support (evidence) for your claims, (3) make sure that you can justify why you think your evidence statements support your claim, and (4) be careful about the evidences that can be used by the other group to refute your claim.
APPENDIX 9: Crisis Management Activity

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CRISIS MANAGEMENT

General criticism:

1. You didn’t reflect what is science behind this idea. Aiming to sell this to science education students or being science ed students as a designer is not science behind it. You are designing an app but do you know how to design it? Do you need to hire someone to create this app? The design of this app, math and coding the software is science behind it. You need to think about this.

2. You are talking about different faculties. Collecting resources for different faculties will make the design and organisation of this app more complicated. As a starting point, it would be better for you if you only aim science education students or EPS department. If you can earn enough and achieve your goals, then, you can aim EHS faculty or different faculties. Furthermore, do you aim to reach only UL students?

3. Budget calculation is a bit confusing. You spend 107,600€ and you earn 165,000€. However, how much shores does the university provide? How do you know that all students will buy this app? If you do not only aim reaching UL students you can think about worldwide. Furthermore, you did not count the money which will be paid to the publishers.

These are the general criticisms and problems detected so far. However, the main issue is about the budget. As mentioned, there is no money paid to the publishers and the publishers do not want to share their content (resources, books, etc) with you as free. All publishers are asking for some payment. How would you solve this problem?
APPENDIX 10: Post-interview Questions

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POST-INTERVIEW

The purpose of the interview is to elicit the participants’ perceptions of “science as a social-institutional system”. For this goal, 24 main interview questions and some sub-questions are posed to each participant of the study. One of the questions is the diagram construction to explain the operation of science and the rest of the interview includes answering the following questions verbally. The total interview time is about an hour for each participant.

1. Is science related to society? Using examples please expand your answer.
2. What do you think about the meaning of the social system?
   2.1. Do you think science is a social system? Please explain your answer.
3. What do you think about the meaning of the institutional system?
   3.1. Do you think science is an institutional system? Please explain your answer.

If the participant is of the opinion that science is a social-institutional system, the interviewer will continue with the questions (3 and 4) below:

4. By using the words provided can you construct a diagram to explain how science works in society? (Give a paper sheet, words, blue tag, post-its). You can add or remove some of the words to construct your diagram.
   4.1. How do you see the relationships and connections between these words?

If the participant is not of the opinion that science is a social-institutional system, the interviewer will continue with the questions (3 and 4) below:

4. By using the words provided can you construct a diagram to explain how science works? (Give a paper sheet, words, blue tag, post-its). You can add or remove some of the words to construct your diagram.
   4.1. How do you see the relationships and connections between these words?

5. Which social or scientific organisations can scientists work for?
6. Do you think scientists do some other activities other than conducting research?
   6.1. What are the kinds of professional activities scientists do?
   6.2. Do you think these activities are necessary? Why?
7. Do you think economics has an impact on actions of scientists? Using examples please explain your answer.

7.1. What kind of impact does the inclusion of economics in science have?

8. Do you think external factors such as the market affect how science works? How?

9. Market means the place where the buyers and sellers interact to trade products and services to fill the supply and demand gap. How are the patents and knowledge transferred from the scientific fields to the market?

10. Where do you think market provide the required knowledge and patents?

11. Have you ever heard the term scientific enterprise previously? If so: in what context? What do you think it means?

12. What about entrepreneurship? What does it mean?

13. What do you think about the inclusion of entrepreneurship in science classes to explain how science works in society?

13.1. Do you think entrepreneurship is important to incorporate into the Junior Certificate science curriculum? Why?

14. What do you think about the inclusion of economics in science classes to explain how science works in society?

14.1. Do you think economics of science is important to incorporate into the Junior Certificate science curriculum? Why?

15. What do you think about improving students’ knowledge on the relationship between academia, market and industry, and its inclusion in science classes to explain how science works?

15.1. Do you think the relationship between academia, market and industry is important to incorporate into the Junior Certificate science curriculum? Why?

16. Describe your experience of the workshops. Can you tell me if you have learned something that you did not have enough knowledge before these workshops?

17. What did you learn from the story-based group discussion?

18. What did you learn from the concept statement preparation?

19. What did you learn from the crisis management activity?

20. What did you feel was most beneficial to you in taking part in the workshops?

21. What aspect did you feel was least beneficial?

22. Do you have suggestions on how these workshops could be improved for the future?

I have no further questions. Do you have anything more you want to bring up, or ask about, before we finish the interview?
APPENDIX 11: Questionnaire

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Name:
Subject:
Gender:
Age:

Please read the statements below and tick the boxes as yes or no.

1. I have completed a module(s) on entrepreneurship and/or economics at post-primary level and/or university.
   Yes □ No □

2. I have an entrepreneurial background.
   Yes □ No □

3. Someone in my family has been involved in entrepreneurial activities and/or comes from an economics background.
   Yes □ No □

In this questionnaire there are 2 parts. In the first part, there are 30 statements related to economics of science, entrepreneurship and how science works in society. Please read each statement and mark your opinion for each statement as strongly agree, agree, neutral, disagree, and strongly disagree. In the second part, there are 3 questions. Please read the questions and write down your opinion in the space provided.

**QUESTIONNAIRE**

**PART 1:**

<table>
<thead>
<tr>
<th></th>
<th>Strongly disagree</th>
<th>Disagree</th>
<th>Neither agree nor disagree (neutral)</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>There is a relationship between science and society</td>
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<tr>
<td>2.</td>
<td>Science is a professional organisation</td>
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<td>3.</td>
<td>Science has its own rules and values</td>
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<td>4.</td>
<td>Scientists only conduct scientific investigations</td>
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<tr>
<td></td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neither agree nor disagree (neutral)</td>
<td>Agree</td>
<td>Strongly Agree</td>
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<td>5.</td>
<td>Scientists can work for industry</td>
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<td>6.</td>
<td>Scientists do professional activities such as publishing research papers and attending conferences</td>
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<td>7.</td>
<td>Scientists spread their scientific knowledge and their research findings by presenting their work at conferences</td>
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<td>8.</td>
<td>Scientists validate their findings by sharing their research results with the scientific community</td>
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<td>9.</td>
<td>It is acceptable for scientists to harm the environment in order to conduct scientific investigations</td>
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<tr>
<td>10.</td>
<td>Scientists are restricted to only working in academic institutions</td>
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<tr>
<td>11.</td>
<td>Scientists should keep their scientific investigation secret at all times</td>
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<td>12.</td>
<td>Scientists who made a discovery or an invention are always the owners of this discovery</td>
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<tr>
<td>13.</td>
<td>There is a relationship between scientists and the industry</td>
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<tr>
<td>14.</td>
<td>Personal factors such as the scientists’ nationality should be taken into account when evaluating scientific claims</td>
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<tr>
<td>15.</td>
<td>Scientific research should benefit and be useful for society</td>
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<td>16.</td>
<td>There is a relationship between the market and the public</td>
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<td>17.</td>
<td>Politics influences scientific research</td>
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<tr>
<td>18.</td>
<td>Science is influenced by the race and gender of scientists</td>
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<tr>
<td>19.</td>
<td>There is a relationship between scientific research and the army</td>
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<tr>
<td>20.</td>
<td>Scientists’ work contributes to various markets like the information technology market</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>Strongly disagree</td>
<td>Disagree</td>
<td>Neither agree nor disagree (neutral)</td>
<td>Agree</td>
<td>Strongly agree</td>
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<tr>
<td>21.</td>
<td>Science and scientific work are influenced by economics</td>
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<tr>
<td>22.</td>
<td>There is a relationship between science and entrepreneurship</td>
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<tr>
<td>23.</td>
<td>Scientific research is funded by the government no matter where it is conducted i.e. universities and industrial places</td>
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<tr>
<td>24.</td>
<td>Companies fund scientific research</td>
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<tr>
<td>25.</td>
<td>There is a relationship between academic institutions and industry</td>
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<tr>
<td>26.</td>
<td>Patents can be purchased by companies or entrepreneurs only for a certain time frame</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>27.</td>
<td>Entrepreneurs transfer the product (including goods, knowledge etc.) from industry and academia to the market</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28.</td>
<td>There is a relationship between academic institutions and the market</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29.</td>
<td>The public is a part of the market (e.g. as buyers, consumers)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>30.</td>
<td>Industrial places produce goods or related services</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

**PART 2:**

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
<th>Please explain your answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Do you think it is important to incorporate entrepreneurship into the Junior Cycle science curriculum?</td>
<td>Yes ☐  No ☐</td>
<td></td>
</tr>
<tr>
<td>2. Do you think it is important to incorporate economics partially into the Junior Cycle science curriculum?</td>
<td>Yes ☐  No ☐</td>
<td></td>
</tr>
<tr>
<td>Question</td>
<td>Answer</td>
<td>Please explain your answer</td>
</tr>
<tr>
<td>----------</td>
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<td>---------------------------</td>
</tr>
<tr>
<td>3. Do you think it is important to include the knowledge of the relationship between the government, academic institution, market and industry into the Junior Cycle science curriculum?</td>
<td>Yes ☐ No ☐</td>
<td></td>
</tr>
</tbody>
</table>

If you are willing to participate in a short interview, please tick the box ☐
APPENDIX 12: Role-play Activity

ACTIVITY: Haber - Bosch process Role Playing (7 Parts-65 min approx.)

PART 1

Story Teller (ST) 1: The “Haber-Bosch” process is very important since ammonia was not sustainable in the 19th century and agriculture was dependent on a limited natural source of ammonia. Discovery of this process helped to feed billions but also to kill millions, and contributed to the pollution of the planet. Throughout the 19th century the demand for nitrates and ammonia for use as fertilisers and industrial feedstocks had been steadily increasing. The main source was mining nitre deposits. At the beginning of the 20th century, it was being predicted that these reserves could not satisfy future demand. Therefore, the research into new potential sources of ammonia became more important.

Scientist 1 (S1): I am the German chemist, Fritz Haber. I did research in physical chemistry at a university and achieved the process of fixing nitrogen from air. This process was later called the Haber or Haber-Bosch process. Myself and my assistant Robert Le Rossignol demonstrated our process in the summer of 1909 by producing ammonia from air. We want to spread this knowledge so we will write some papers.

Scientist 2 (S2) (working for the industry): My name is Carl Bosch. I am a scientist working for the BASF Company. We heard about the Haber process. This discovery is of importance for the large-scale synthesis of fertilisers and explosives. As the BASF Company, we will try to purchase it. We can also ask Haber to work for us and we can fund him for further research. Therefore, maybe we can use Haber’s discovery to produce some fertilisers.

QUESTION TIME-1 (7 min)

PART 2

ST 2: Haber accepts the offer and starts working with Bosch for the BASF Company. Bosch starts scaling up Haber’s table-top machine to industrial-level production.

S1 and S2: We succeeded. This process of converting atmospheric nitrogen to ammonia is faster now. Thanks to this process, nitrogen from the atmosphere was synthesised to solve a problem that faced farmers across the globe.

ST 3: Ammonia was first manufactured using the Haber process on an industrial scale in 1913 by the BASF Company. After a short time, the BASF Company started to produce sustainable ammonia by this process and facilitated the production of millions of tons of fertiliser. Therefore, the good use of this process saved millions of people starving to death. Haber and Bosch were later awarded Nobel prizes, in 1918 and 1931 respectively for their work. Haber and Bosch are the inventors but the BASF Company bought this invention. Therefore the BASF Company became the owner. However, Haber and Bosch became an eponym of this by naming this discovery as Haber-Bosch process.

This method is used by the industry to produce fertilisers and to contribute solving the food production problem for half the world’s current population.

QUESTION TIME-2 (7 min)

SILA KAYA, UL
PART 3

An Entrepreneur (in the market): This invention seems great to satisfy the fertiliser need in the market. I can buy this product and sell it in the market. I can contribute to solve the world’s fertiliser issue by transferring this product and knowledge from industry and academia, to the market.

A person representing a company in the market: We can buy this product from an entrepreneur or from the industrial places and sell it to the consumers. By increasing the food production we can contribute to solve the world’s fertiliser issue.

QUESTION TIME-3 (7 min)

PART 4

ST 4: The market is the place where buyers and sellers interact to exchange products and services. The market can request anything (e.g. knowledge, patents) from scientists working at the academic institutions or at the industrial places for their further needs.

Later on the story, another issue arises: World War I. During World War I, the production of munitions required large amounts of nitrate.

Germany (representing the State/Government): The Allies had access to large sodium nitrate deposits controlled by British companies. I have no such resources. I heard the fame of Haber. We can ask Haber if he wants to conduct a research on chemical weapons during the World War I.

QUESTION TIME-4 (7 min)

ST 5: Being asked to conduct research on chemical weapons puts pressure on Haber because Haber’s wife, who is also a chemist, does not want him to work on chemical weapons. Haber chooses to be funded and to work for the government over his wife. His wife breaks up with him. Synthetic ammonia from the Haber process is used for the production of nitric acid, a precursor to the nitrates used in explosives. Haber’s work causes the death of millions of people.
PART 5 (8 min)

Read the following words shown in the box. You can select a word or more from the box which you think is related to one of the categories in the table. Therefore, you can use all or some of the words in the box to fill in the table.

For example, academic institutions are related to the category of “Academia”.

Also, you can select a word or more from the story you have read which you think is related to one of the categories in the table.

For example, Germany is related to the category of “Government”.

By using the story you have read and the words provided, please fill in the following table. You can also write some other words that you think are related to the categories in the table.

<table>
<thead>
<tr>
<th>Words:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic institutions</td>
<td>Animals</td>
<td>Buyers</td>
</tr>
<tr>
<td>Consumers</td>
<td>Companies</td>
<td>Discoveries</td>
</tr>
<tr>
<td>Entrepreneurs</td>
<td>Currency Exchange Office</td>
<td>Industry</td>
</tr>
<tr>
<td>Inventions</td>
<td>Knowledge</td>
<td>Market</td>
</tr>
<tr>
<td>Patents</td>
<td>Plants</td>
<td>Products</td>
</tr>
<tr>
<td>Professional Activities</td>
<td>Research</td>
<td>Scientists</td>
</tr>
<tr>
<td>(e.g. writing papers)</td>
<td>Sellers</td>
<td>Stock broker</td>
</tr>
<tr>
<td>Government</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ACADEMIA</th>
<th>MARKET</th>
<th>INDUSTRY</th>
<th>GOVERNMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>e.g. ACADEMIC INSTITUTIONS</td>
<td></td>
<td></td>
<td>e.g. GERMANY</td>
</tr>
</tbody>
</table>

353
When you complete PART 5, please continue with PART 6 on Page 4.

PART 6 (15 min)

By using the categories provided in PART 5, please construct a diagram to explain how science works in society. You can add or remove some of the words that you think is not very important to explain how science works in society. You can categorise or sub-categorise the words. For example:

Academia

Academic institutions

...xxxx...

.xxx.

You can use the arrows ( → ↔ ) to show the relationships between the categories, sub-categories or words that you have written in the table in PART 5. You can make as many links as you want. This diagram does not need to have a certain shape.

Please construct your diagram on the extra sheet provided.

When you complete PART 6, please continue with PART 7 on Page 5.

PART 7 will be completed individually.
PART 7 (8 min)

Please answer the following questions. These questions will be answered *individually*. You can use an extra sheet if necessary. If you are using an extra sheet please don’t forget writing your name on it.

1. What do you think about the role of entrepreneurship in how science works in society?
2. What do you think about the role of economics in how science works in society?
3. What do you think about the relationship between the academic institutions, industry, market and the
APPENDIX 13: Role Cards of the Role-play Activity

ACADEMIC INSTITUTIONS

**SCIENTIST 1:** I am the German chemist, Fritz Haber. I did research in physical chemistry at a university and achieved the process of fixing nitrogen from air. This process was later called the Haber or Haber-Bosch process. Myself and my assistant Robert Le Rossignol demonstrated our process in the summer of 1909 by producing ammonia from air. We want to spread this knowledge so we will write some papers.

INDUSTRY

**SCIENTIST 2:** My name is Carl Bosch. I am a scientist working for the BASF Company. We heard about the Haber process. This discovery is of importance for the large-scale synthesis of fertilisers and explosives. As the BASF Company, we will try to purchase it. We can also ask Haber to work for us and we can fund him for further research. Therefore, maybe we can use Haber’s discovery to produce some fertilisers.

MARKET

**AN ENTREPRENEUR:** This invention seems great to satisfy the fertiliser need in the market. I can buy this product and sell it in the market. I can contribute to solve the world's fertiliser issue by transferring this product and knowledge from industry and academia, to the market.

**STORYTELLER (ST)**: The “Haber-Bosch” process is very important since ammonia was not sustainable in the 19th century and agriculture was dependent on a limited natural source of ammonia. Discovery of this process helped to feed billions but also to kill millions, and contributed to the pollution of the planet. Throughout the 19th century the demand for nitrates and ammonia for use as fertilisers and industrial feedstocks had been steadily increasing. The main source was mining nitre deposits. At the beginning of the 20th century, it was being predicted that these reserves could not satisfy future demand. Therefore, the research into new potential sources of ammonia became more important.

**ST:** Haber accepts the offer and starts working with Bosch for the BASF Company. Bosch starts scaling up Haber’s table-top machine to industrial-level production.

**A PERSON REPRESENTING A COMPANY:** We can buy this product from an entrepreneur or from the industrial places and sell it to the consumers. By increasing the food production we can contribute to solve the world’s fertiliser issue.

GOVERNMENT

**GERMANY:** The Allies had access to large sodium nitrate deposits controlled by British companies. I have no such resources. I heard the fame of Haber. We can ask Haber if he wants to conduct a research on chemical weapons during the World War I.
ST-3: Ammonia was first manufactured using the Haber process on an industrial scale in 1913 by the BASF Company. After a short time, the BASF Company started to produce sustainable ammonia by this process and facilitated the production of millions of tons of fertiliser. Therefore, the good use of this process saved millions of people starving to death. Haber and Bosch were later awarded Nobel prizes, in 1918 and 1931 respectively for their work. Haber and Bosch are the inventors but the BASF Company bought this invention. Therefore the BASF Company became the owner. However, Haber and Bosch became an eponym of this by naming this discovery as Haber–Bosch process. This method is used by the industry to produce fertilisers and to contribute solving the food production problem for half the world's current population.

ST-4: The market is the place where buyers and sellers interact to exchange products and services. The market can request anything (e.g. knowledge, patents) from scientists working at the academic institutions or at the industrial places for their further needs.

Later on the story, another issue arises: World War I. During World War I, the production of munitions required large amounts of nitrate.

ST-5: Being asked to conduct research on chemical weapons puts pressure on Haber because Haber's wife, who is also a chemist, does not want him to work on chemical weapons. Haber chooses to be funded and to work for the government over his wife. His wife breaks up with him. Synthetic ammonia from the Haber process is used for the production of nitric acid, a precursor to the nitrates used in explosives. Haber's work causes the death of millions of people.
APPENDIX 14: Question Time Cards of the Role-play Activity

**QUESTION TIME-1**
1. Where do you think scientists can work at?
2. What kinds of activities do scientists do in the workplace? Why? (e.g., Haber, Le Rossignol)
3. What is the relationship between academic institutions and the industry? In other words, what can scientists and industrial places provide to each other?

**QUESTION TIME-2**
1. What do you think industrial places sell their product?
2. Where do you think the industrial places sell their product?
3. What is the relationship between the industry and the market? In other words, what do industry and the market provide to each other?

**QUESTION TIME-3**
1. What is the role of an entrepreneur in the market?
2. Who do you think are the buyers and sellers in the market?
3. What is the relationship between science and the market?

**QUESTION TIME-4**
1. What would be the relationship between the government and science? In other words, what can the government and scientific institutions do to improve the quality of life for the average person?
2. If you were Haber, would you work for the government to produce chemical weapons during the war? Why?
APPENDIX 15: Further Information on How Question Time Cards are Targeting Different Components of the SIS of Science and the SAMI Cycle Framework

Each of the first four parts had question cards which are called “Question Time” targeting different components of the SIS of science and the SAMI cycle framework. Thus, thirdly, Question Time cards were developed for each part. Part 1 included elements of the top right of the SAMI cycle framework, such as a scientist working in academia and another scientist working in industry. Therefore, in Question-Time 1, mainly the relationship between science and industry was questioned. The SAMI cycle framework and targeted Question Times are presented in the figure below.

Figure: The SAMI cycle framework and the parts targeting question times
The targeted components of the SAMI cycle framework (state/government, academia, market, industry) and the targeted domains (SIS of science in NOS, EOS and entrepreneurship) with each role card in PART 1 are presented in table below.

Table: Targeted themes, domains, and learning outcomes of part 1 in the role-play

<table>
<thead>
<tr>
<th>Role</th>
<th>Targeted theme in the SAMI cycle framework</th>
<th>Targeted domain in the SAMI cycle framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Story teller</td>
<td></td>
<td>NOS, EOS</td>
</tr>
<tr>
<td>Scientist 1</td>
<td>Academia</td>
<td>NOS, EOS</td>
</tr>
<tr>
<td>Scientist 2</td>
<td>Industry</td>
<td>NOS, EOS</td>
</tr>
</tbody>
</table>

Part 2 included the elements of the right part of the cycle, such as transfer of a product from industry to the market. Thus, in Question-Time 2, the relationship between industry and market was questioned. The targeted components of the SAMI cycle framework (state/government, academia, market, industry) and the targeted domains (SIS of science in NOS, EOS and entrepreneurship) with each role card in PART 2 are presented in table below.

Table: Targeted themes, domains, and learning outcomes of part 2 in the role-play

<table>
<thead>
<tr>
<th>Role</th>
<th>Targeted theme the SAMI cycle framework</th>
<th>Targeted domain the SAMI cycle framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Story teller</td>
<td></td>
<td>NOS, EOS</td>
</tr>
<tr>
<td>Scientist 1&amp;2</td>
<td>Industry</td>
<td>NOS, EOS</td>
</tr>
<tr>
<td>Story teller</td>
<td></td>
<td>NOS, EOS</td>
</tr>
</tbody>
</table>
Part 3 involved elements of the bottom right part of the cycle, such as an entrepreneur and a person representing a company in the market. Hence, in Question-Time 3, mainly the relationship between academia and market was questioned. The targeted components of the SAMI cycle framework (state/government, academia, market, industry) and the targeted domains (SIS of science in NOS, EOS and entrepreneurship) with each role card in PART 3 are presented in table below.

Table: Targeted themes, domains, and learning outcomes of part 3 in the role-play

<table>
<thead>
<tr>
<th>Role</th>
<th>Targeted theme the SAMI cycle framework</th>
<th>Targeted domain in the SAMI cycle framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>An entrepreneur</td>
<td>Market</td>
<td>NOS, EOS, entrepreneurship</td>
</tr>
<tr>
<td>A person representing a company</td>
<td>Market</td>
<td>NOS, EOS, entrepreneurship</td>
</tr>
</tbody>
</table>

Part 4 was covering different elements of the cycle, for example the market, government/state. Furthermore, it included some social aspects of NOS, such as social values and scientific ethos which are also illustrated at the centre of the SAMI cycle framework. Therefore, in Question-Time 4, mainly the role of state/government in how science works in society and scientific ethos and social values that scientists adopt was explained. The targeted components of the SAMI cycle framework (state/government, academia, market, industry) and the targeted domains (SIS of science in NOS, EOS and entrepreneurship) with each role card in PART 4 are presented in table.

Table: Targeted themes, domains, and learning outcomes of part 4 in the role-play

<table>
<thead>
<tr>
<th>Role</th>
<th>Targeted theme in the SAMI cycle framework</th>
<th>Targeted domain in the SAMI cycle framework</th>
</tr>
</thead>
<tbody>
<tr>
<td>Story teller</td>
<td></td>
<td>NOS, EOS, entrepreneurship</td>
</tr>
<tr>
<td>Germany</td>
<td>State/government</td>
<td>NOS, EOS, entrepreneurship</td>
</tr>
</tbody>
</table>
APPENDIX 16: The Interview Conducted at the End of the Once-off PSTE

PART 1: EXPLORING THE VIEWS AND EXPERIENCES OF THE WORKSHOP(S)

Explanation and Clarification: When I say activity it is the role playing activity. When I say workshop it is the whole process including the short presentation.

1) Can you describe your experience of the workshop? (Positives, negatives, challenges…)
   a. What did you or did you not like about the activity? Why? (Will give the activity sheets and start talking about it)
   b. Which part of the activity was the most beneficial for you? Why?
   c. Which part of the activity was the least beneficial for you? Why?
2) What do you think you have learned/gained from participating in this workshop?
   a. Do you think your thinking and understanding changed in any way? If so, in what way? Which part do you think changed your thinking and understanding?
3) Is there anything that you would change (remove or add) in this workshop? Which part(s)? Why? (Suggestions on how this workshop could be improved for the future)

ONLY FOR THE PILOT RESEARCH GROUP PARTICIPANTS:

You have been involved in this research since the beginning. Here I will ask you some general questions about last year’s and this year’s activities. (Provide all the activities we have done so far)

1) What did you learn in general throughout this research?
2) Which one was more effective on improving your learning; last year’s or this year’s workshops? Why?
3) Can you compare in which part of the research you have improved your knowledge more? (Group discussion, Concept Statement, Diagram Construction, Role Playing) Why do you think so?
   a) Which part was catchier? Why?

PART 2: UNDERSTANDING OF TOPIC and EDUCATIONAL APPLICATIONS

4) As you know, nature of science is the framework of the new JC specification and as we said before, there is a part called “science in society” in nature of science strand in this JC specification. What do you think about the social aspects of nature of science?
a) Has your understanding of nature of science been changed by attending this workshop? If yes, how did it change? In which part? If not, why do you think so?

5) What do you think is the relationship between economics and science?
   a) Did the workshop inform your understanding? Please explain your answer.
   b) Has your understanding of the relationship between economics of science and the JC Specification changed during this workshop? If yes, how did it change? In which part? If not, why do you think so?

6) How do you see the relationship between economics of science and the JC Specification?
   a) Why do you think economics of science should be incorporated into JC?
   b) Where would this fit in the JC Specification?

7) What does entrepreneurship mean to you?

8) What do you think you learned about the relationship between entrepreneurship and science by participating in this workshop? In which part?

9) How do you see the relationship between entrepreneurship and the JC Specification?
   a) Why do you think entrepreneurship should be incorporated into JC?
   b) Where would this fit in the JC Specification?
   c) Has your understanding of the relationship between entrepreneurship and the JC Specification changed during this workshop? If yes, how did it change? In which part? If not, why do you think so?

10) How do you see the relationships and connections between the government, academia, market and industry?

11) What do you think you learned about the relationship between the government, academia, market and industry by participating in this workshop? In which part?
    a) Has your understanding of the relationship between the SAMI Cycle framework and the JC Specification changed during this workshop? How?

12) How do you see the relationship between SAMI Cycle framework and the JC Specification?
    a) Why do you think SAMI Cycle framework should be incorporated into JC?
    b) Where would this fit in the JC Specification?
## APPENDIX 17: Grouping Information and Folder Contents

<table>
<thead>
<tr>
<th>Group Name</th>
<th>Number of Students</th>
<th>Group Folder Content</th>
<th>Personalised Folder Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>6</td>
<td>• Role-play activity PART 5 and PART 6</td>
<td>• Pen</td>
</tr>
<tr>
<td>E</td>
<td>4</td>
<td>• Eight blank sheets • Question Time cards</td>
<td>• Research information sheet</td>
</tr>
<tr>
<td>F</td>
<td>6</td>
<td>• Role-play activity PART 1 to 4</td>
<td>• Consent form</td>
</tr>
<tr>
<td>G</td>
<td>5</td>
<td>• Role-play activity PART 7</td>
<td>• Pre-questionnaire</td>
</tr>
<tr>
<td>H</td>
<td>5</td>
<td>• Post-questionnaire</td>
<td>• Role cards specific to the person</td>
</tr>
<tr>
<td>I</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
APPENDIX 18: Example Analysis of Anne’s Pre and Post-Interviews

ANN (PRE-INTERVIEW)

[00:28:57.23] Interviewer: What about entrepreneurship? What does it mean?

[00:29:04.03] Anne: Ammm... Someone makes their own business.

[00:29:09.13] Interviewer: Ok. So... Is that all? They are just doing their own business or are they doing anything else?

[00:29:18.02] Anne: Ammm... Work to do it I suppose.

[00:29:25.00] Interviewer: Ok. Do you think entrepreneurship has a place in how science works in society?


[00:29:33.28] Interviewer: How do you think it has a place?

[00:29:34.20] Anne: Because the research you do link to making projects and then that can make a product and then that can lead to making business. So if someone is good enough to make some ideas themselves they can form their own business but they obviously need to test it and do experiments and things and then maybe what materials work best and what don’t work best...

[00:29:59.04] Interviewer: Then they can start their business and they can do it...

[00:30:01.22] Anne: Yeah.

[00:30:05.28] Interviewer: What do you think about the inclusion of entrepreneurship in science classes to explain how science works in society?

[00:30:14.26] Anne: Ammm....

[00:30:19.21] Anne: Yeah, it would be good to include it because it probably make science more interesting and maybe might motivate students to do science more but like... people are concerned with learning the information for science... They are not concerned with actually doing the entrepreneurship of it... They are like “I just want to learn what is in my modules”. Not what entrepreneurship is... Do you know...

[00:30:55.16] Interviewer: So do you think entrepreneurship is applicable in science classes?

[00:30:58.24] Anne: Yeah. It is! It would make it more interesting but I think the main concern is just trying to learn what you need to know but I suppose still it would make learning science more interesting...

Concerns about entrepreneurship

[00:31:01.81] Interviewer: Ok but why do you think they are not really concerned about this?

[00:31:17.01] Anne: Because everyone is more concerned about the content of the actual science like actually learning what they need to know.
Anne: It can be a person, it can be a group of people who come up with a project or want to have an idea or something that they want to develop more and they can develop a project or they can get money to develop something. It's that they have an idea they want to develop it.

Interviewer: It's they have an idea that they want to develop it?

Anne: Yeah.

Interviewer: Ok. Do you think entrepreneurship has a place in how science works in society?

Anne: Yes.

Interviewer: Why and how it has a place?

Anne: Because society will influence the entrepreneurs and then the society will be influenced by the entrepreneurs as well.

Interviewer: How would you explain the role of entrepreneurship in how science works in society?

Anne: How science works in society... Entrepreneurs have ideas, develop things, develop research, and develop whatever and that may need more scientific knowledge, more research.

Interviewer: Ok. Do you think scientists can become entrepreneurs?

Anne: Yeah like an entrepreneur-scientist.

Interviewer: Now, we will talk about the educational part more. What do you think about the inclusion of entrepreneurship in science classes to explain how science works in society?

Anne: Students will probably find science more interesting. If they think like "I can discover something and also make profit of it" they'd probably be more engaged in science.

Interviewer: Do you think entrepreneurship is just about the money?

Anne: No like it can be money led but if someone wants to invent a car or the sake of inventing they can do it like developing a software.

Interviewer: Do you think entrepreneurship is important to incorporate into the Junior Certificate science curriculum?

Anne: I think it would help to motivate the students and engage them. They can they would see the benefit in science more.
<table>
<thead>
<tr>
<th>Anne (pre)</th>
<th>Professional Activities (PA)</th>
<th>Scientific Ethos (SE)</th>
<th>Social Values (SV)</th>
<th>Social Certification and Dissemination (SCD)</th>
<th>Social Organisations and Interactions (SOI)</th>
<th>Political Power Structures (PP)</th>
<th>Economics of Science (EOS)</th>
<th>Entrepreneurship (ENT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA</td>
<td>Comparing results, looking at each other’s results</td>
<td>Publishing, comparing results, looking at each other’s results, publishing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>Comparing results, looking at each other’s results</td>
<td>Tests on people, tests on animals</td>
<td>Collaborating, working together, comparing results, looking at each other’s results, to make their own business they need to test it and do experiments and see what works</td>
<td>Collaborating, working together, university-organisation link</td>
<td></td>
<td>Doing research on an area to make money, people studying science to make money or because they like it, they are not going to do it if they are not getting any money to do research, if there is funding or money scientists will do more in that area, market affects science because scientists will do research where all the money is, to make their own business they need to test it and do experiments and see what works</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SV</td>
<td>Tests on people, tests on animals</td>
<td>A lot of tests to make sure it is suitable for use</td>
<td>Work with or eat each other, or do research on them (people-animals-plants)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCD</td>
<td>Publishing, comparing results, looking at each other’s results, publishing</td>
<td>Collaborating, working together, comparing results, looking at each other’s results, to make their own business they need to test it and do experiments and see what works</td>
<td>A lot of tests to make sure it is suitable for use</td>
<td>Collaborating, working together, produced medicine goes into production and a factory buys it</td>
<td></td>
<td>Make something and bring it into production to be sold, to make their own business they need to test it and do experiments and see what works</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SOI</td>
<td>Collaborating, working together, university-organisation link</td>
<td>Collaborating, working together, produced medicine goes into production and a factory buys it</td>
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<td></td>
<td>Factory and lab relationship, making up business this way (seaweed), research in labs and production of it, produced medicine goes into production and a factory buys it, patents will be funded by universities-factories or organisations if there is a gap in the market</td>
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<td>PP</td>
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<td>making up business this way (seaweed), patents will be funded by universities-factories or organisations if there is a gap in the market</td>
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<tr>
<td>EOS</td>
<td>Doing research on an area to make money, people studying science to make money or because they like it, they are not going to do it if they are not getting any money to do research, if there is funding or money scientists will do more in that area, market affects science because scientists will do research where all the money is, to make their own business they need to test it and do experiments and see what works.</td>
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<td></td>
<td>Make something and bring it into production to be sold, produced medicine goes into production and a factory buys it, to make their own business they need to test it and do experiments and see what works.</td>
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<td>Factory and lab relationship, making up business this way (seaweed), research in labs and production of it, produced medicine goes into production and a factory buys it, patents will be funded by universities, factories or organisations if there is a gap in the market.</td>
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<td>ENT</td>
<td>Market affects science because scientists will do research where all the money is, to make their own business they need to test it and do experiments and see what works.</td>
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<td>Make something and bring it into production to be sold, to make their own business they need to test it and do experiments and see what works.</td>
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<td>Making up business this way (seaweed), patents will be funded by universities, factories or organisations if there is a gap in the market.</td>
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<td>Making up business this way (seaweed), make something and bring it into production to be sold, market affects science because scientists will do research where all the money is, patents will be funded by universities, factories or organisations if there is a gap in the market, things in BT Young scientists is a scientific enterprise for example secondary school students conduct experiments or do research and come up with a business idea, research leads to project and products and this leads to making business, to make their own business they need to test it and do experiments and see what works, the reason for getting funding is the market, economy leads to what is wanted in the market.</td>
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<td>Professional Activities</td>
<td>Scientific Ethos</td>
<td>Social Values</td>
<td>Social Certification and Dissemination</td>
<td>Social Organisations and Interactions</td>
<td>Political Power Structures</td>
<td>Economics of Science</td>
<td>Entrepreneurship</td>
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APPENDIX 20: The Result of the Normality Test

![Tests of Normality Table]

APPENDIX 21: The Correlation Coefficient Results between Overall Score, Social Aspects of NOS and the SAMI Cycle Framework in the Pre-test

![Correlation Table]

**. Correlation is significant at the 0.01 level (2-tailed).
APPENDIX 22: The Correlation Coefficient Results between Overall Score, Social Aspects of NOS and the SAMI Cycle Framework in the Post-test

<table>
<thead>
<tr>
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<th>Post</th>
<th>socialNOS2</th>
<th>SAMI2</th>
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<td>.884**</td>
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<td></td>
<td>Sum of Squares and Cross-products</td>
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<td>1644.360</td>
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<td>Covariance</td>
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<td>33.558</td>
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<td>50</td>
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<tr>
<td><strong>socialNOS2</strong></td>
<td>Pearson Correlation</td>
<td>.596**</td>
<td>.596**</td>
</tr>
<tr>
<td></td>
<td>Sig. (2-tailed)</td>
<td>.000</td>
<td>.000</td>
</tr>
<tr>
<td></td>
<td>Sum of Squares and Cross-products</td>
<td>1644.360</td>
<td>1059.520</td>
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<tr>
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<td>Covariance</td>
<td>33.558</td>
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<tr>
<td><strong>SAMI2</strong></td>
<td>Pearson Correlation</td>
<td>.596**</td>
<td>.596**</td>
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<td></td>
<td>Sig. (2-tailed)</td>
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<td>Sum of Squares and Cross-products</td>
<td>1494.620</td>
<td>584.840</td>
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<td>Covariance</td>
<td>30.502</td>
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**. Correlation is significant at the 0.01 level (2-tailed).
## APPENDIX 23: The EOS Categorisation of Once-off PSTE

<table>
<thead>
<tr>
<th>Theme</th>
<th>Participants’ views</th>
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<tbody>
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<td><strong>Supporting the inclusion of EOS:</strong></td>
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<tr>
<td>• to understand the starting point of science</td>
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<tr>
<td>• to have an understanding of the importance of money</td>
<td></td>
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<tr>
<td>• to understand economic climate of their world</td>
<td></td>
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<tr>
<td>• to understand the world we live in better</td>
<td></td>
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<tr>
<td>• to gain different perspective of science to benefit society</td>
<td></td>
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<tr>
<td>• to see that science is connected to economy under certain circumstances in the real world</td>
<td></td>
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<tr>
<td>• to learn about their connection</td>
<td></td>
</tr>
<tr>
<td>• to educate students about how economics has an effect on them and everything around them</td>
<td></td>
</tr>
<tr>
<td>• to increase students’ understanding and interest in science</td>
<td></td>
</tr>
<tr>
<td>• to be aware of how science and economics interlinked</td>
<td></td>
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<tr>
<td>• to have an understanding of how it affects everyday life</td>
<td></td>
</tr>
<tr>
<td>• to understand the role of science and economics</td>
<td></td>
</tr>
<tr>
<td>• to understand why science is important</td>
<td></td>
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<tr>
<td>• to give them an understanding of the part science plays in society with respect to the economy</td>
<td></td>
</tr>
<tr>
<td>• to allow students to see the point of studying science a bit better, to make students see it as more relatable to their lives</td>
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<tr>
<td>• to see importance of economics as science as a driver of technology</td>
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<tr>
<td>• to make students aware of the market and what’s going on around them</td>
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<tr>
<td>• to understand the impact and importance of science in industry</td>
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<tr>
<td>• to understand the money etc involved and may them want to keep studying science as they see the money involved that can be earned, to encourage more students to be interested in science</td>
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<tr>
<td>• to see how science contributes to society, to see the cross-curricular links and see the bigger picture of science, not observing it as a subject through one lens</td>
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<tr>
<td>• to develop students’ awareness of the true cost implications that science has</td>
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<tr>
<td><strong>Improving understanding of science and economics</strong></td>
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<tr>
<td>• to improve the knowledge of supply and demand and various competitive markets which will benefit them</td>
<td></td>
</tr>
<tr>
<td>• to improve economics knowledge which will benefit students when entering into the working world</td>
<td></td>
</tr>
<tr>
<td>• to gain the knowledge on the intersdisciplinarity of science and job opportunities</td>
<td></td>
</tr>
<tr>
<td>• to learn how to implement their (students) ideas</td>
<td></td>
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<tr>
<td>• having this knowledge would be beneficial in adult life</td>
<td></td>
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<tr>
<td>• to give a broader range of knowledge on science and economics and how they work together</td>
<td></td>
</tr>
<tr>
<td><strong>Economics of science as a skill</strong></td>
<td></td>
</tr>
<tr>
<td>• a new skill, which would benefit them in the long run to understand more about politics, gov etc</td>
<td></td>
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<tr>
<td>• money management skill</td>
<td></td>
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<tr>
<td>• ability to use their knowledge outside if school and develop whatever they like</td>
<td></td>
</tr>
<tr>
<td>• economic skills are needed to be successful and well rounded</td>
<td></td>
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<tr>
<td>• skill to handle own finances</td>
<td></td>
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<tr>
<td>• skill to manage money</td>
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<tr>
<td>• fundamental life skill</td>
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<td>• money efficiency skill</td>
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</table>
APPENDIX 24: The Role-play Activity Results of Each Group

Each groups’ understanding of the relationship between academia-industry, academia-market, industry-market and government-academia are presented in the following. While the results are being presented, the group opinions are supported by the quotes written by individuals in the group.

Group A was comprised of six participants. They were of the opinion that state/government, academia, market and industry are all interconnected and they could not exist without each other. They constructed a diagram illustrating how science works in society, which is presented in Figure 33.

Figure 33: Group A diagram illustrating how science works in society

As seen in Figure 33, state/government, academia, market and industry are represented as they all are connected through the society. Furthermore, in Question Time parts, they discussed these relationships, and explained the academia-industry relationship by stating that:

academics provide employees to work in industry, industry might be a career path, industry provides funds and scholarships, and uses scientists’ methods/theories/inventions to improve large scale operations.

(Group A, Question Time)
There is a two-way relationship between the industry and the market, such as producing products and providing expertise and goods/services. This group (Group A) referred to industry and market relationship by addressing that “industry makes products for the market, and they provide goods and services to each other”. Market and academia also provide knowledge/products, funding and expertise. Concerning the academia and market relationship, they stated that:

without science, markets cannot carry out their investigations or research in order to develop. Market may request funding, expertise, knowledge and skills from scientists to further need of the market.

(Grupo A, Question Time)

The government has an impact on academia, and they can provide funding or knowledge to each other. Group A also explained the relationship between the government and academia. They were of the opinion that “government provides funding, grants and facilities for scientists to work and discover” and “science provides the government with products inventions, processes, drugs and new ways to do things”. As seen, the role of funding is emphasised by Group A within all dual relationships in the SAMI cycle framework.

Group B was comprised of five participants. They were of the opinion that state/government, academia, market and industry are all interlinked and interdependent. P11 defined this as a symbiotic relationship. They were of the opinion that academic institutions and industry provide “workforce, knowledge, opportunities, expansion, and improvement” to each other. Furthermore, they were of the opinion that “industry meets the demand of the market (supply and demand) and market influences what the industry produces” as the relationship between market and industry. Concerning the relationship between academia and market, they stated that:

science develops products that market wants. If market or scientist has an idea for a product, they consult each other.

(Grupo B, Question Time)

Even though they stated that “government provides funding to scientists and controls what scientists do” as the relationship between academia and government,
this relationship was not demonstrated in their diagram illustrating how science works in society, which is presented in Figure 34.

![Figure 34: Group B diagram illustrating how science works in society](image)

As seen in Figure 34, even though the relationship between government, market and industry relationship were presented in the government box, the relationship between academia and government was not presented. Other relationships between academia, market and industry were also presented in this figure.

Group C was comprised of five participants. When the participants of the group were asked about the relationships, they stated that “academic institutions provide graduates to work in the industry and new findings useful for the industry” and “industrial places sell their product to schools, labs and universities” concerning the relationship between academia and industry. Regarding the market-industry relationship, they mentioned that “market is the consumer for industry and industry is the producer for market”. Concerning the academia-market relationship, they were of the opinion that “market and scientific research drives each other”. They mentioned the government-academia relationship:

- government can provide support through funding to science and scientists can provide findings and important discoveries in healthcare and technology for government.

(Group C, Question Time)
However, a direct relationship between academia and government was missing from their diagram presented in Figure 35.

Figure 35: Group C diagram illustrating how science works in society

As seen in Figure 35, indirect relationships were represented between state/government, academia, market and industry. Additionally, in the individual part (Part 7), two participants did not provide their opinion of the relationship between state/government, academia, market and industry, only one participant mentioned that they all are linked to each other but did not explain how. This might be because of their low understanding of the SAMI cycle framework. The participants’ lack of understanding between the relationships is also evident in Figure.

Group D was comprised of six participants. They were of the opinion that state/government, academia, market and industry have an interwoven/interrelated relationship with each other. P23 called this relationship a symbiotic relationship. They constructed a diagram illustrating how science works in society, which is presented in Figure 36.
Even though Figure 36 is a basic representation, it includes all of the relationships.

While the industry is represented as a bridge between the market and academia, the government is represented all around them. Furthermore, in Question Time parts, Group D participants discussed these relationships, and they explained the academia-industry relationship by stating that:

academic institutions provide theory and knowledge behind practical industrial practices/improvements. Industry provides scientists with funding and direction, and practical training for young scientists e.g. apprenticeship.

(Grupo D, Question Time)

Within this context, they also mentioned that “industry bridges the gap between theoretical science and practical goods, and puts science into practice”. They also provided an example of the academia-market relationship stating that “science develops the new products for the market and identifies gaps in the market, and the market needs scientists to provide knowledge”, and emphasised how the government controls science through funding, and science provides vital knowledge for the government.

Group E was comprised of four participants. Two participants were of the opinion that state/government, academia, market and industry were all linked and this is an significant relationship, whilst the remaining two did not respond. They constructed a diagram illustrating how science works in society, which is presented in Figure 37.
In part 5, entrepreneurship was categorised in industry, products, consumers and sellers were categorised in the market and knowledge, whilst research and scientists were categorised in academia. Therefore, academia, market and industry relationship is illustrated in Figure 37. Even though the government was not mentioned here, the relationship between academia and government was addressed as “government provides money for funding scientists’ experiments and scientists provide information” in the Question Time. Furthermore, they explained the academia-industry relationship by stating that:

industry provides money, labs, research, qualified students, advertisement and sponsorship to academic institutions, and scientists provide initiative, new ideas, safety equipment, possible business, new solutions to problems and a fresh approach to research.

(Group E, Question Time)

Concerning the academia and market relationship, they stated that “science brings new products to the market and the market sells these products to the consumers”.

Group F was comprised of six participants. They were of the opinion that state/government, academia, market and industry are all related and interconnected. They constructed a diagram illustrating how science works in society, which is presented in Figure 38.
Figure 38 shows that the state/government, academia, market and industry are all interconnected as participants of the Group F mentioned. Furthermore, in the Question Time, they explained the academia-industry relationship by stating that “industry and academia are connected through money/funding, staff, resources, educated people and access to the customer”. They also addressed the relationship between academia and the market as in “science creates products and makes things possible for the market”. Concerning the government - academia relationship, they stated that:

the government can provide resources for the scientists or dictate what research is carried out and prioritise research/experiments. Scientists can provide new ideas/strategies/research that can benefit or change society.

(Group F, Question Time)

Group G was comprised of five participants. While three participants were of the opinion that state/government, academia, market and industry are all connected, one participant did not answer the question, and P38 only talked about the relationship between academia and industry. They constructed a diagram illustrating how science works in society, which is presented in Figure 39.
Figure 39: Group G diagram illustrating how science works in society

In Figure 39, while government, academia and industry were directly written, they used buyers and sellers to represent the market, which is evident in their categorisation in Part 5. Group G stated that government, academia, market and industry are all interconnected through society. Furthermore, in the Question Time, concerning the academia-industry relationship, they stated that “academia provides the workforce for the industry, and industry turns the research knowledge into products for the public”. They also talked about the market-academia relationship, and highlighted that the “market provides income/money to science, and the market needs science for products”. Regarding the government-academia relationship, they only stated that “government funds the research”. Looking at Figure 39, it can be seen that the only relationship between academia and government is through research and experiments.

Group H was comprised of five participants. They were of the opinion that state/government, academia, market and industry are all interconnected and they could not exist without each other. While P41 called this as a symbiotic relationship, P42 was of the opinion that this relationship has pros and cons.
Participants of the Group H constructed a diagram illustrating how science works in society, which is presented in Figure 40.

![Figure 40: Group H diagram illustrating how science works in society](image)

In Question Time parts, concerning the academia-industry relationship, it was stated that “academia and industry provide research, money (funds) and the skilled workforce to each other”. However, group members did not present any relationship between academia and industry in Figure 40. They explained the academia and market relationship by stating that:

market is central to the research, and need the knowledge and facts from academic institutions. Scientists need to be funded by the market and they need to get their ideas from the market.

(Group H, Question Time)

Concerning the relationship between academia and government, they addressed what government and scientists provide to each other as “safety, weapons for protection, health services, funding, troops (army) and improved safety methods”.
Also, the relationship between army, government and science was brought up. However, they did not represent this relationship in Figure 40.

Group I was comprised of five participants. While four participants were of the opinion that state/government, academia, market and industry are all interlinked and depend on each other, P46 did not mention the relationship but only mentioned the role of academic institutions. They constructed a diagram illustrating how science works in society, which is presented in Figure 41.

Figure 41: Group I diagram illustrating how science works in society

Figure 41 illustrates an interconnection between state/government, academia, market and industry. This interconnection is also discussed in Question Time. Group members were of the opinion that academia and industry provide each other with “knowledge, graduates, new ideas and sample labs”. They explained the relationship between market and academia by stating that “products made in science, sold in the market”. Concerning the relationship between the government and academia, they indicated that “government provides funding and advises scientists on their research”. Government advice to scientists’ research draws attention here that is also included as government control and power on scientists in political power structures.
Group J was comprised of three participants (Anne, Mary and Lisa) who were involved in the continuous PSTE previously. They were of the opinion that state/government, academia, market and industry are all interlinked and rely on each other. They constructed a diagram illustrating how science works in society, which is presented in Figure 42.

Figure 42: Group J diagram illustrating how science works in society

Figure 42 illustrates that state/government, academia, market and industry are all interconnected and there are bilateral relationships between categories. In Question Time, Anne, Mary and Lisa discussed these relationships further and concerning the academia-industry relationship, they stated that:

academic institutions provide students and an educated workforce that maybe useful for industry -they might have new ideas etc. Industry often provides money to help with research in the academic institutions. They might also help sponsor master degrees etc. for students.

(Group J, Question Time)
Concerning the academia and market relationship, they were of the opinion that “they can work independently but not efficiently without each other” and stated that:

market can sell the products to universities. Market can also request from academia patents and ideas to solve problems. Demand of the market is placed on scientists.

(Group J, Question Time)

They also addressed the government-academia relationship and stated that:

they fund each other. Government may need or want things and puts pressure on scientists to make and create things, and the government supply money for research. Scientists can fulfil government’s wants and needs.

(Group J, Question Time)
APPENDIX 25: The Frequency of the Answers of Each Question in the Once-off PSTE

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PUBLICATIONS AND CONFERENCES

Publications and attended conferences throughout this study are presented in this section.

PUBLICATIONS

Refereed Journal Articles


Book Chapters


Other Publications


CONFERENCES


Kaya, S., Erduran, S. and Birdthistle, N. (2016) Enhancing pre-service science teachers’ entrepreneurial skills and attitudes in Nature of Science and
Science Education, European Science Education Research Association (ESERA) Summer School, Czech Republic, August 22nd - 26th.


