Science & Education (2018) 27:457–478
https://doi.org/10.1007/s11191-018-9990-y

ARTICLE

Looking at the Social Aspects of Nature of Science in Science Education Through a New Lens

The Role of Economics and Entrepreneurship

Sila Kaya [1] • Sibel Erduran [2] • Naomi Birdthistle [3] • Orla McCormack [1]

Published online: 14 August 2018

Abstract
Particular social aspects of the nature of science (NOS), such as economics of, and entrepreneurship in science, are understudied in science education research. It is not surprising then that the practical applications, such as lesson resources and teaching materials, are scarce. The key aims of this article are to (a) synthesize perspectives from the literature on economics of science (EOS), entrepreneurship, NOS, and science education in order to have a better understanding of how science works in society and (b) illustrate how such a synthesis can be incorporated in the practice of science education. The main objectives of this article are to (1) argue for the role and inclusion of EOS and entrepreneurship in NOS and re-define entrepreneurship in the NOS context; (2) explore the issues emerging in the "financial systems" of the Family Resemblance Approach (FRA) to NOS and propose the inclusion of contemporary aspects of science, such as EOS and entrepreneurship, into NOS; (3) conceptualize NOS, EOS, and entrepreneurship in a conceptual framework to explain how science works in the society; and (4) transform the theoretical knowledge of how science operates in society into practical applications for science teaching and learning. The conceptual framework that we propose illustrates the links between State, Academia, Market and Industry (the SAMI cycle framework). We suggest practical lesson activities to clarify how the theoretical discussions on the SAMI cycle framework can be useful and relevant for classroom practice. In this article, science refers to physics, chemistry, and biology. However, we also recommend an application of this framework to other sciences to reveal their social-institutional side.

✉ Sila Kaya
sila.kaya@ul.ie

1 EPI-STEM National Centre, University of Limerick, Limerick, Ireland

2 Department of Education, University of Oxford, Oxford, UK

3 Department of Business Technology and Entrepreneurship, Swinburne University of Technology, Melbourne, Australia

1 Introduction

During the past few decades, research interest in interdisciplinary characterization of science, which is the cross-curricular links between different domains, has become prominent in the science education literature. Some of these interdisciplinary research interests are "Socio-Scientific Issues" (Lee et al. 2012; Sadler and Dawson 2012), "Science-Technology-Society-Environment" (Pedretti and Nazir 2011), "History and Philosophy of Science" (Matthews 2014), and "Nature of Science" (Erduran 2014; Lederman et al. 2002). The focus in this article is nature of science (NOS) in science education, particularly concerning some social aspects of NOS, such as economics of science (EOS) and entrepreneurship.

There is considerable literature on NOS, for example, the characterization of NOS and assessment methods of NOS (Allchin 2011; Erduran and Dagher 2014; Irzik and Nola 2011; Lederman et al. 2002). These studies argue that learning about NOS is highly beneficial for students. For example, Driver et al. (1996) highlighted the potential benefits of learning about NOS, such as understanding the process of science and appreciating science as a pivotal element of contemporary culture. However, a substantial shortcoming of the research studies is that the social aspects of NOS are underrepresented (Jiménez-Aleixandre 2015). There is research emphasizing the importance of (1) using entrepreneurship in science classes (Board of Education and Discipline 2013; Deveci and Seikkula-Leino 2016; European Commission 2012; Martin et al. 2017; The Entrepreneurial School 2014–2015); (2) EOS for science education (Allchin et al. 2014; Erduran and Mugaloglu 2013; Matthews 2014); and (3) integrating NOS into science syllabi (DES 2015). However, the link between entrepreneurship, EOS, and NOS has not been explored. Therefore, the current NOS approaches lack a coherent overarching framework for understanding some contemporary social aspects of NOS, such as EOS and entrepreneurship, and their relationships. The purpose of this article is to incorporate the literature from EOS, entrepreneurship, NOS, and science education to have a better understanding of social aspects of NOS, the role of EOS, and entrepreneurship in NOS. Furthermore, we aim to introduce the SAMI cycle framework as a way of conceptualizing these concepts (EOS, entrepreneurship, NOS) and the relationship between them. The SAMI cycle framework aims to explain how science works in society by illustrating the links between the State/government, Academia, Markets, and Industry.

The primary objectives of this article are to (1) argue for the role and inclusion of EOS and entrepreneurship in NOS; (2) explore the issues emerging in the "financial systems" of the Family Resemblance Approach (FRA) to NOS and propose the inclusion of contemporary aspects of science, such as EOS and entrepreneurship into NOS; (3) conceptualize NOS, EOS, and entrepreneurship in a conceptual framework (the SAMI cycle framework) to explain how science works in the society; and (4) transform the theoretical knowledge of how science works in the society into practical applications for science teaching and learning. To achieve these goals, we rely on the Family Resemblance Approach (FRA), which is one of the NOS approaches proposed for science education (Erduran and Dagher 2014; Irzik and Nola 2011).

2 Nature of Science (NOS)

This section presents the contemporary NOS approaches, the rationale for relying upon the FRA and introduces the FRA by focusing on its economic aspect. There have been many studies attempting to characterize NOS in science education (Abd-El-Khalick 2012; Allchin

2011; Irzik and Nola 2014; Matthews 2012; McComas et al. 1998). Some of the recent NOS approaches proposed for science education are the “consensus view”; the “features of science” (FOS); the “whole science” and the “family resemblance approach” (FRA). In these approaches, the role of economics is highlighted in the social aspects of NOS either explicitly or implicitly. For example, the “consensus view” refers to economics in social-cultural embeddedness, the “whole science” mentions economics as funding/economics, the FRA mentions the importance of economics in general, and the extended FRA embraces “financial systems” as one of the categories in the social-institutional system (SIS) of science.

NOS is characterized as a comprehensive area of research in science education incorporating perspectives based on cognitive, epistemic, social, political, scientific, and economic aspects of science education, and it aims to understand how science works (Erduran and Dagher 2014; Irzik and Nola 2014). The FRA as one of the NOS approaches was adapted from philosophy into NOS and revised by Irzik and Nola (2011, 2014). In the FRA for NOS, Irzik and Nola (2011) suggested investigating dissimilarities as well as similarities of each science discipline and building up a set of characteristics for each of them. Furthermore, they claimed that science cannot be distinguished from social, cultural, historical, and political factors. Aligned with this, Erduran and Dagher (2014) have extended and elaborated on the FRA to develop a more comprehensive and thorough account of an FRA-based NOS account in science education. In Erduran and Dagher’s (2014) version of FRA, the four categories offered by Irzik and Nola (2014) and three other categories proposed by Erduran and Dagher (2014), such as “financial systems”, were gathered under a single umbrella called “science as a social-institutional system” to re-conceptualize NOS holistically. Thus, there are three systems in NOS, namely cognitive, epistemic, and social-institutional system (Erduran and Dagher 2014). Here, our focus is on the social-institutional system of science in NOS. There are seven elements of SIS of science, which are:

1. Professional activities
2. Scientific ethos
3. Social values of science
4. Social certification and dissemination
5. Social organizations and interactions
6. Political power structures
7. Financial systems

Therefore, financial systems are explicitly included in the extended FRA in NOS. Within this context, the extended FRA not only does embrace the social aspects of NOS, such as economic aspects, but also includes and details a broader set of categories by exemplifying the transformation of the theoretical ideas into classroom practice. The extended FRA (Erduran and Dagher 2014) is the most comprehensive and informed approach about the economic aspect of NOS with the direct inclusion of financial systems.

Although financial systems are included in the extended FRA, the reference to economics in the interdisciplinary research areas, such as NOS, has been reasonably broad with little theoretical input from the formal discipline of EOS (Erduran and Mugaloglu 2013). Therefore, in the next section, EOS is introduced conceptually by providing the literature from its formal discipline and explored through the organizational and economic dynamics that govern scientists and scientific communities. Furthermore, the place of EOS in science education is also discussed.

3 Economics of Science (EOS)

This section introduces EOS conceptually by providing the literature from the "economics of science". While introducing EOS, its elements are specified and thematized systematically. At the end of Section 3, relevant science education literature to EOS is also briefly presented to help identifying the role of EOS in NOS and science education. During the twentieth and twenty-first centuries, many studies have been conducted on EOS (Audretsch et al. 2002; Diamond 2008; Erduran and Mugaloglu 2013; Irzik 2007; Mirowski and Sent 2008; Romer 2001; Stephan 1996). For example, Mirowski and Sent (2002) highlighted the place of economics in science by stating that "deep down, all scientists understand that at some fundamental level, there is some sort of economic process or processes channeling and fortifying their science; it is indisputable that someone, for some reason, has been picking up the tab" (p.1). Furthermore, Diamond (2008) addressed the aims of EOS as "to understand the impact of science on the advance of technology, to explain the behavior of scientists, and to understand the efficiency and inefficiency of scientific institutions" (p.1). Between these studies, the most dominant themes in the science education context are science and scientists in industry, funding of research at academic institutions, and commodification and commercialization of science. Therefore, these themes are scrutinized in the following paragraphs.

The role of *science and scientists in the industry* has been discussed in numerous studies (Diamond 2008; Irzik 2007; Mirowski and Sent 2002; Polanyi 1957; Radder 2010; Romer 2001; Stephan 1996). Within this context, the contribution of science and scientists to sustaining the development of industrial places and institutions such as universities and research centers has been emphasized. For example, during World War II, scientists and engineers working on joint projects brought interdisciplinary collaboration with new goals such as expanding academic research capabilities and cooperating with industry (Etzkowitz 2008). In 1994, there were members of the National Academy of Sciences coming from industry. There can be different kinds of supply and demand relationships between science and industry. We provide two examples of such relationships. In the first relationship, academia supplies graduates or scientific advisory for companies (Stephan 1996). As an example, 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. 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). Many scientists are employed in the private sector as CEOs, or they run their own business while they continue to work at their university (Irzik 2013). Based on academic inventors' publications and their interactions with scientists in industry, technology transfer offices identify commercial opportunities. Due to the dissemination of research findings, potential industrial partners may be identified to provide funding that moves the findings toward utilization (Etzkowitz 2008).

Funding of research at academic institutions is of high importance. Funding for academic research can be provided from different sources such as the government, research centers, industries, and business organizations. For example, in the USA, funding for research and development (R&D) comes primarily from the federal government, business, and industry. While the government supports scientific research due to its importance to defense and economic growth and due to the need to subsidize the production of the public good knowledge, business and industry support science due to their desire to innovate (Stephan 1996). There are different ways of acquiring funding, such as through scientists' own institutions (e.g. research centers and universities) or by applying for a grant to funding agencies. Sometimes industries or the private sector may also offer to fund universities in exchange for the results of scientific research and for the shared or sole ownership of patents (Erduran and Mugaloglu 2013; Irzik 2007; Radder 2010). Some of the benefits of this approach are that scientists can spend all their time working directly on their research rather than spending time writing research proposals and completing application forms. Scientists may also submit their proposals to apply for grants. At the end of a competitive application process, they may receive funding. The scientists who follow the grant application process take on many of the characteristics of entrepreneurs (Stephan 1996). Some of the benefits of following the grant application process are that peer-reviews promote the quality and sharing of information rather than secrecy. However, the grant application process may govern the scientific domains that the research is conducted. That is, scientists might focus on researching the scientific domains, in which more funding is available, rather than focusing on the social value of the research due to their need for funding to conduct their scientific investigations. Thus, even though one of the primary purposes of science is the pursuit of knowledge driven by curiosity, sometimes, the government funding and its associated recognition and status may drive the research. Furthermore, both funding acquirement processes may be adopted within the same country, as in Europe. However, this financial relationship between academia and industry can have a negative impact on research studies. For instance, Resnik and Elliott (2013) researched the influence of financial relationships on research credibility. They found that financial relationships should be considered when evaluating research since these relationships can affect different aspects of scientific investigations such as study design, data collection, and data analysis. Additionally, 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.

Funding opportunities for scientists have also been increased by *commodification and commercialization of science* (Irzik 2007). Commodification and commercialization of academic research have recently garnered some interest worldwide, which has resulted in some scientific disciplines being more influenced than others (e.g. the impact on molecular biology vs cosmology). Irzik (2013) referred to commodification and commercialization of science by stating 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 licensing" (p. 2376). Likewise, Radder (2010) has argued that the commodification and commercialization of science is related to selling the academic expertise of researchers in academic institutions and the results of their enquiries. According to Oliver (2004), the relationship between academia and industry has an impact on the growth of commercialization of academic science and the transformation of research results into intellectual properties/patents as marketable commodities. Thus, here, we define the commodification and commercialization of science as turning the results of scientific knowledge into marketable commodities by the mechanisms of intellectual property. There are benefits and drawbacks of commodification and commercialization. For example, commercialization contributes to increasing the innovation in academia, to provide new job opportunities, to develop university-industry relationships, knowledge capitalization and, therefore, to economic and social development (Etzkowitz 2008; Irzik 2013). Moreover, it allows funders to make profits through research, which increases funding opportunities for scientists to conduct their research projects. However, as mentioned previously, commodification and commercialization of science can lead to research interests being governed by commercial and corporate interests. As a result, research findings may be biased (Krimsky 2004), and reward systems in science may be affected. A non-market reward structure in science aims to incentivize scientists to behave in socially responsible ways to produce the public good "knowledge". Based on Stephan (1996), primarily, we can talk about three kinds of reward structures:

1. Priority: This includes the award of priority of discovery and publication, which are also related to recognition. Some of their different forms are eponymy and the Nobel Prize. Priority creates a form of intellectual property, and financial rewards can be one of the consequences of priority.
2. Property rights: This is to define how a resource is used and by whom it is owned. Patenting is one of the examples, and financial remuneration can be one of the outcomes of this. Intellectual property rights are also included in this category.
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.

Many issues can also emerge in relation to the reward structure, such as ownership, fraud, negotiation of contracts with industry and the government, monitoring human subjects and dangerous materials research (Mirowski and Sent 2002), scientific contests, inequality, the patent race (Stephan 1996), publishing for only financial awards, monopoly of research, and secrecy. Based on these points and the relationship between science and industry, how scientific effort is organized, monitored, used, and rewarded in the industry is of importance.

To identify the importance of EOS in science education, some examples of EOS are given. There are some studies that implicitly or explicitly refer to economics in science education (Allchin 2011; Allchin et al. 2014; Carter 2008; Erduran and Dagher 2014; Erduran and Mugaloglu 2013; Irzik 2013; Irzik and Nola 2014; Lederman et al. 2002; Matthews 2014); however, there are not many studies that profoundly examine it. The studies that examine economic dimensions of science most profoundly and explicitly are presented here briefly. Erduran and Mugaloglu (2013) discussed the economic dimension of science and its role in science education. They presented two rationales for examining the intersection of EOS and science education: (1) investigating what economic features of science should be infused in science education is relevant to the characterization of science, and (2) the development and training of future scientists is reliant on the foundation and the maintenance of the scientific enterprise through the education system. They also provided an example activity to use in second-level education, which includes students aged 12–18 approximately. Furthermore, as mentioned previously, Erduran and Dagher (2014) included financial systems in NOS and provided two examples to implement financial systems in science education. The first example was Linnaeus' classification of organisms and its relation to the whaling industry. This example aimed to show the relationship between science, financial systems, and "political power structures". The second example was the epidemiology of dioxin, which included the issues related to profit-making in industry, social interactions between scientists and their employers, the values of social utility and respect for human life. This example aimed to apply financial systems and social values of science in science education. Furthermore, the inclusion of EOS is essential in order to create responsible citizens who are scientifically literate, who are 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 2014). We believe that science education should support the ideal of the autonomy of science, which is free from social, economic, and political forces, and the idea that science should be done in the pursuit of knowledge, not profit. However, this cannot be achieved by ignoring the economy and science relationship. Thus, students should be educated by increasing their awareness of the advantages and disadvantages of economics for science.

There is also some research highlighting an enterprising feature of science along with its other features. For instance, according to Irzik and Nola (2014), "science is many things all at once: it is an investigative activity, a vocation, a culture, and an enterprise with an economic dimension …" (p.8). Likewise, Erduran and Mugaloglu (2013) stated that characterization of science is related to economic features of science, and the maintenance of the scientific enterprise. However, the role of entrepreneurship is under-represented in the SIS of science. Thus, in the next section, entrepreneurship is introduced in its formal field, along with the relevant science education literature to entrepreneurship.

4 Entrepreneurship

This section aims to define and introduce entrepreneurship in its formal field, and how it is re-defined in the NOS and science education context based on the characteristics in its formal field. Then, the relevance of entrepreneurship to science is presented in order to help identify the place of entrepreneurship in NOS and science education. The section is concluded by presenting the relevant entrepreneurship literature in science education. Even though there are many studies defining entrepreneurship in its formal field, there is no consensus on which definition to follow. 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 create a new business (Bruyat and Julien 2001), a broader concept focuses on personal qualities and the environment rather than new business creation. In this article, the broader concept of entrepreneurship has been considered in science education. Table 1 presents the definitions of entrepreneurship in its broader concept in the twentieth and twenty-first centuries.

According to Shapero (1975):

> in almost all of the definitions of entrepreneurship, there is agreement that we are talking about a kind of behavior that includes: (1) initiative taking, (2) the organizing and reorganizing of social and economic mechanisms to turn resources and situations to practical account, (3) acceptance of risk or failure (Shapero 1975, cited in Hisrich and Peters 2002, p.10)

As seen in Table 1, although organizing, initiative taking, and risk-taking skills can be seen clearly, there is no such emphasis on failure. Learning about failures in science is essential in science education (Allchin 2011); therefore, this may be another feature when defining entrepreneurship in the NOS context. Furthermore, realizing opportunities is another common word in the table. This seems a new feature added to the broader definition of entrepreneurship in Table 1 at the end of the 1970s.

Table 1 Definitions of entrepreneurship in order of the year

Authors	Definitions
Schumpeter (1934)	Carrying out new combinations of a firm's operation including different dimensions, such as new products, new services, new source of raw materials, new methods of production, new markets and the new forms of organization.
Hoselitz (1952)	Coordination of productive resources, an introduction of innovations and the provision of capital.
Timmons (1989)	The ability to create and built something from practically nothing, it is initiating, doing, achieving and building an enterprise or organization rather than watching, analyzing or describing one.
Shane and Venkataraman (2000)	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.
Hisrich and Peters (2002)	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.
Allen (2003)	The process of organizing. This organization 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.
Birdthistle et al. (2007)	To transfer the knowledge, service or product between the fields of inquiry.
Rindova et al. (2009)	Efforts to bring about new economic, social, institutional, and cultural environments through the actions of an individual or group of individuals.

Even though there is a body of research on entrepreneurship and entrepreneurship in science education, there is lack of research on defining entrepreneurship in NOS and science education contexts. But before doing so, we should introduce the relevance of entrepreneurship to science and economics. The relationship between science, economic growth, and entrepreneurship has recently been discovered (Etzkowitz 2008; Sanders 2007). Furthermore, as mentioned in Section 3, science is also characterized as an *enterprise with an economic dimension* (Erduran and Dagher 2014; Erduran and Mugaloglu 2013; Irzik and Nola 2014). This relationship affected 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, we re-defined entrepreneurship in NOS and science education by analyzing the common words of the definitions in Table 1, and by including the word "failure" as this is an important activity within science. Entrepreneurship in NOS can be defined as:

> the process of establishing new economic, social, institutional, cultural and scientific environments or organizations to create future products and services by realizing the opportunities and their possible failures and using required resources (Kaya et al. 2018)

The following classic example of entrepreneurship can be considered to clarify how this definition fits into science. This example also identifies the links between scientists, engineers, entrepreneurs, and the market. A scientist discovered the scientific knowledge behind the touchpad and an engineer invented the touchpad by using this knowledge. Another scientist or engineer invented and patented activating the screen-lock by sliding back and forth. Steve Jobs combined these patents and launched the iDevices, such as the iPhone, as a new product. In this example as in our entrepreneurship in NOS definition, someone realized an opportunity in the market, considered the possibility of failure, established a company using required resources and combining the patents, developed new products, and distributed them in the market. Therefore, this person is called an entrepreneur. Furthermore, scientists, engineers, and entrepreneurs utilized each other's work throughout the process, which also affected the market and the society.

Scientists and entrepreneurs are usually thought to have different aims, values, and working ways. Due to this, academic institutions and the government facilitate the meeting of these groups. For example, in Ireland, the government supports academia to enable commercialization of scientific research and provides the platform for academics to meet entrepreneurs through innovation parks and centers at the universities. There are initiatives through the commercialization of research funded by the government or 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 (Etzkowitz 2008; Etzkowitz and Leydesdorff 1998; Oliver 2004). For example, Maci (2017) introduced Professor Per-Simon Kildal, who was a scientist, an educator, and a business person, as one of the entrepreneurial scientists. Another way of bringing scientific and entrepreneurial minds together and of facilitating the emergence of entrepreneurial scientists is incubator units and programs. These are multi-disciplinary units/programs located in academia bringing students together from all disciplines. These units are funded by the state and usually supported by industry (Etzkowitz 2008). In dealing with the demands placed in scientific enterprises, labs and incubators, scientists need to know about entrepreneurship and may need entrepreneurial skills (Sarasvathy and Venkataraman 2011). Moreover, 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). Similarly, Stephan (1996) examined science and scientists in industry, reward systems, and so on and discussed how increased opportunities for entrepreneurial behavior affect the practice of science. Furthermore, Etzkowitz (2008) argued that entrepreneurial training should be a part of general education since new organization formations have increasingly become common in all aspects of life.

In order to situate the place of entrepreneurship within the public-school environment, a body of research has been conducted in science education worldwide (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; Lepistö and Ronkko 2013; Nwakaego and Kabiru 2015; Martin et al. 2017). Kleppe (2002), for example, conducted research in the USA and found that K-12 educators need to integrate the fundamentals of inventing, innovation, and entrepreneurship into all levels of the curriculum. Buang et al. (2009) conducted research in Malaysia and proposed five entrepreneurial science-thinking steps to use for primary and secondary school science teaching. Bacanak (2013) found that teachers had inadequate knowledge on entrepreneurship in Turkey and emphasized the necessity of in-service training on improving the teachers' understanding of entrepreneurship and entrepreneurial skills. 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.

As Sarasvathy and Venkataraman (2011) stated, entrepreneurship is not only a career option but also a widespread driver of social change. There may be criticisms of entrepreneurship and neoliberal politics (Foucault et al. 2008; Brown 2003). The impact of the neo-liberal regime on the entrepreneurial university is indisputable. However, the aim of this article is not to crown any political view; instead, the aim is to point to the growing interest of entrepreneurship in scientific domains, particularly in science education, and to increase the awareness of its possible outcomes. We take the view that curricular relevance is sufficient reason to investigate how to explore these themes in science education. Thus, in the next section, we problematize the financial systems in NOS, present what the inclusion of EOS and entrepreneurship can provide to science education, and propose an alternative way to financial systems.

5 Problematizing Financial Systems in NOS and an Alternative Way to Overcome the Issue

In this section, we discuss and evaluate the EOS terminology used in the extended FRA (Erduran and Dagher 2014) because, as mentioned in Section 2, this approach is the most comprehensive and informed one about the economic aspect of NOS with the explicit inclusion of financial systems. Our goal is to problematize the financial system in NOS and understand how NOS and science education can be enriched through the inclusion of EOS and entrepreneurship as an alternative way.

In financial systems in NOS, economics-related terminology was used, such as *economic resources* and *commodification of science*. However, the informativeness and comprehension of the system were very limited. Within this context, we criticize this system because:

1. Mediation of economic resources for distribution of resources in science and the actions of scientists was presented superficially.
2. Commodification and commercialization of science were introduced but not explained.
3. The system was limited to funding aspect of EOS.

We believe that this system is underdeveloped and not comprehensive. Likewise, Jiménez-Aleixandre (2015) criticized the features of the SIS of science in NOS as being underdeveloped. Therefore, our primary criticisms are:

1. The title—financial systems—is misleading the reader and very limited.
2. The system is not well-structured.
3. There is not enough information taken from the formal discipline of EOS to develop this system.
4. The system is not comprehensive.

The reason for our first criticism is that even though the word "finance" is only related to money, Erduran and Dagher (2014) use this term while providing similar context with EOS. To overcome this issue, to declare the driving force of EOS in NOS and to make this system more holistic and comprehensive, we propose changing financial systems to "economics of science in nature of science" (EOS in NOS). "Economics" deals with the context of financial systems, such as distribution, the behavior of scientists and money, more comprehensive than finance and without misleading the reader. Thereby, EOS would fit better with the scope of financial systems. Concerning the structure and the context drawn from EOS literature, we propose three main themes, which emerged in Section 3, to structure EOS in NOS, namely *science and scientists in industry*, *funding of research at academic institutions*, and *commodification and commercialization of science*. These themes are also conspicuous in the science education literature (Erduran and Dagher 2014; Erduran and Mugaloglu 2013; Irzik 2013). Furthermore, in Section 4, we discussed the relevance of entrepreneurship to EOS and science education. Due to this relevance and the need for industry-ready graduates, we also propose including entrepreneurship into NOS. Overall, as an alternative way to financial systems, we propose "contemporary social aspects of NOS" which is comprised of EOS and entrepreneurship. Furthermore, we propose structuring EOS in NOS under the three themes mentioned.

We believe that the inclusion of contemporary social aspects in NOS and science education can provide many benefits, such as:

1. Increase students' awareness on economics-related issues
2. Teach students how funding and grants affect the operation of science
3. Provide a greater understanding of cross-curricular links of science
4. Make science more relatable to students' everyday life and realize the everyday applications of science
5. Contribute to career opportunities for students by providing them with self-employment as a career opportunity
6. Contribute to the social and economic development of a country.

Based on what we have presented so far, a relationship between the state, academia, market, and industry starts to come forth. However, there are still unanswered questions; for example, what should we understand when someone asks the question of how science works in society? What would be the relationships between the state, academia, industry and the market? Thus, in the next section, we answer these questions and introduce the SAMI cycle framework.

6 The SAMI Cycle Framework

6.1 The Development of the SAMI Cycle Framework

Based on what has been presented so far, we propose the SAMI cycle framework, which is developed as a way of conceptualizing NOS, EOS, entrepreneurship, and the relationship between them. The SAMI cycle framework has been developed in three stages: NOS as a foundation, EOS to build upon the process, and entrepreneurship to complete the process.

6.1.1 Stage 1—NOS as a Foundation

In this stage, the extended FRA in NOS is used (Erduran and Dagher 2014). The first draft of the SAMI cycle framework emerged at the end of this stage and is presented in Fig. 1. NOS aims to understand how science works (Allchin 2011; Erduran and Dagher 2014; Irzik and Nola 2014; Martins and Ryder 2015), and this article targets the social aspects of NOS. Therefore, firstly, the process of how science works in society was studied. The SIS of science in the extended FRA (Erduran and Dagher 2014) informed the development process of the SAMI cycle framework. Academic institutions and industrial places emerged in "social organizations and interactions" and "financial systems" as scientists' workplaces. The precursors of the organization and the relationship between state, academia, and industry also emerged here. The activities that scientists are involved in their workplaces came up in "professional activities" and the extended FRA. These scientific activities include conducting basic and/or applied research, producing scientific knowledge, acquiring funding, and performing professional activities, such as attending conferences and publishing. "Social certification and dissemination" indicated that research results are certified and disseminated, which is represented by an arrow going out from what scientists do in their workplace. "Political power structures" referred to the influence of the state/government on science. Furthermore, "financial systems" and "political power structures" referred to the role of government and determined it as providing funding. When we questioned how the scientific knowledge was utilized, "social values of science" and "scientific ethos" represented the core ethical and moral dimensions of the science and society by referring that the scientific knowledge is shared and used for social utility. Since the framework is to explain how science works in society, society was represented by a large circle.

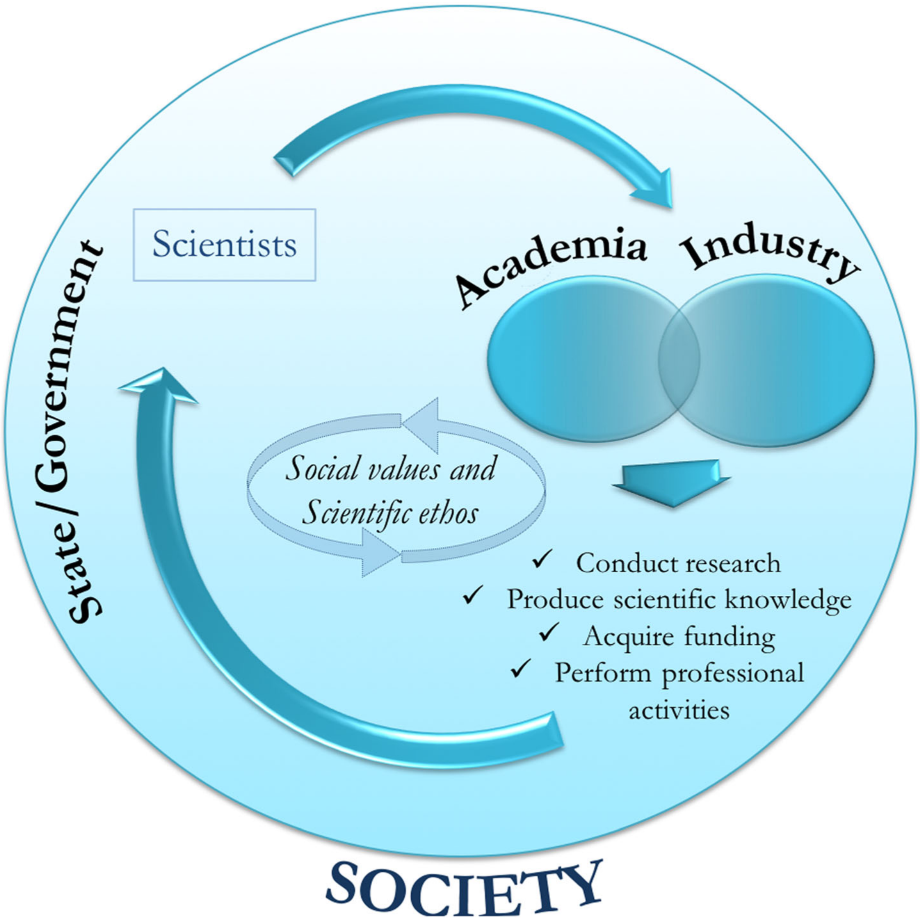

Fig. 1 First draft of the SAMI cycle framework

6.1.2 Stage 2—EOS to Build upon the Process

As seen in Fig. 2, even though the relationship between academia and industry started to emerge, this relationship was not fully informed. Therefore, in stage 2, the EOS literature is utilized. In particular, the scope of EOS, which was determined in Section 3, informed the SAMI cycle framework. The second draft of the SAMI cycle framework emerged at the end of this stage and is presented in Fig. 2. In the figure, contributions of EOS to explain how science works in society are highlighted in red. The relationship between scientists and the market and the role of the market were highlighted in red. However, the authors left the color transparent since the relationship is vague and incomplete. Starting from academia and industry relationship, which was underdeveloped in stage 1, "Science and scientists in the industry" clarified the relationship between academia and industry. Within this context, cooperation between academia and industry was identified (Etzkowitz 2008), and the supply and demand relationship between academia and the industry was determined (Stephan 1996). 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). "Funding of research at academic institutions" indicated that the government, industry, and/or business provide funding for the scientific research (Erduran and Mugaloglu 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). This is represented in the cycle within scientific ethos. "Commodification and commercialization of science" referred to 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 is highlighted here. 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. However, sometimes they are transferred to the market, which is represented by an arrow going out of "Academia" and "Industry" in Fig. 2. At this stage, the role of the market and the two-way relationship between scientists and the market in the process started to appear, but they were neither clearly defined nor well informed.

6.1.3 Stage 3—Entrepreneurship to Complete the Process

As seen in Fig. 2, although the market started to emerge in the process, the role of the market and its relationship were not fully informed, and it was incomplete. Thus, in stage 3, the entrepreneurship literature was utilized. In particular, the broader definitions of entrepreneurship (see Table 1), and emerging areas of entrepreneurship in NOS, such as entrepreneurship in science and entrepreneurial scientists, informed the process. The final version of the SAMI cycle framework emerged at the end of this stage and is presented in Fig. 3. To complete the process of how science operates in society, we looked into how the scientific knowledge is utilized in the market and how the scientific products are transferred to the market. Within this context, it was identified 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). This is also described by Shapero (1975, cited in Hisrich and Peters 2002) as turning resources into practical accounts. Furthermore, the relationship between the buyers and sellers was determined. Entrepreneurs can have a role here as buyers or sellers. There are other buyers such as consumers and other sellers such as companies. Here, it is worth mentioning that companies may be

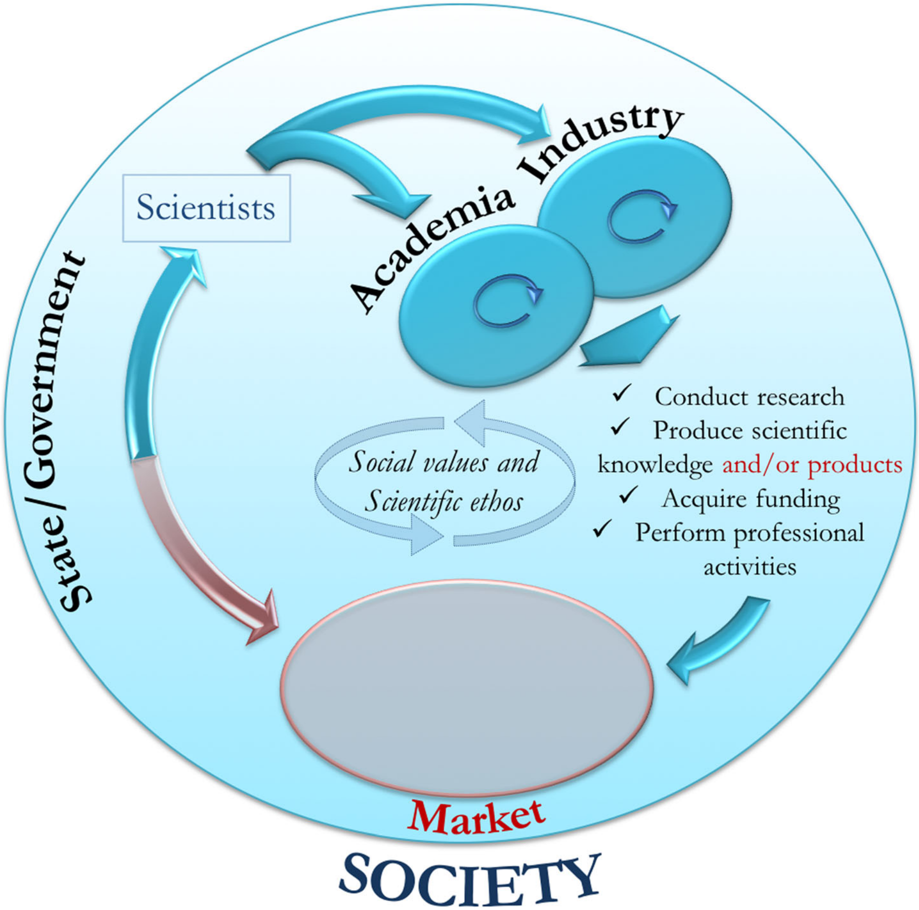

Fig. 2 Second draft of the SAMI cycle framework

involved either in production as industries or in the market as buyers or sellers. Supply and demand between buyers and sellers are also represented with cyclical arrows in the market. It was then identified that the demand in the market creates a two-way relationship between the science and 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, if there is a further need and if it cannot be supplied within the market, entrepreneurs take this as an opportunity and may inform the scientists working in academia and/or industry about the need. Here, scientists can also realize the need themselves and conduct basic or applied research on the issue. Therefore, the relationship between market and scientists is represented as a two-way relationship. Finally, the role of state/government was identified as critical to ensure the existence of free and efficient markets since once markets are left alone, they most likely become inefficient and unfree (Foucault et al. 2008; Polanyi 1957). 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. For example, state/government affects the funding, grant system, and therefore the market type and market economy.

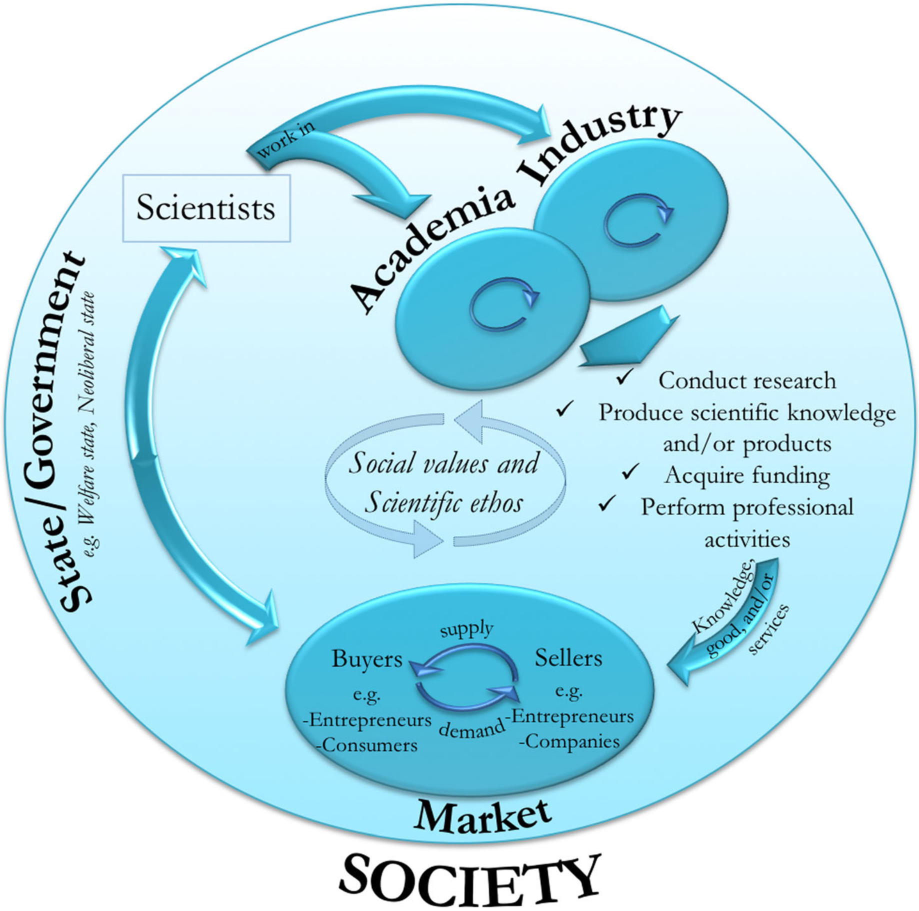

Fig. 3 The SAMI cycle framework

Figure 3 illustrates a nuanced, profound way of comprehending how scientists work within and across social and scientific institutions, and how they interact with one another and with stakeholders. Within this context, it also represents the relationship between State-Academia-Market and Industry. Here, while industry represents 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 of some goods or services meet (Black et al. 2009). Therefore, while industry refers to the production, the market refers to where the products are sold or, sometimes, the target group for the product. There can be different societies with different state politics, and the SAMI cycle framework can be adapted to different societies. Based on the introduction of the SAMI cycle framework, the relevance of the SAMI cycle framework to science education and its benefits are explored in the following section.

6.2 Justifying the Contributions of SAMI Cycle Framework

In this section, we discuss two benefits of the SAMI cycle: to improve second or third-level students' and teachers' understanding and to improve the economy and society.

Firstly, the SAMI cycle framework provides a practical and visual tool which could help enhance not only the comprehensive understanding of the social aspects of how science operates in society, but also students' and teachers' awareness of the relevance of science within state, academia, industry and the market, and their relationship with one another. Furthermore, this framework adopts a holistic view of the subject matter and illustrates the links between concepts by breaking down the subject boundaries. Within this sense, this aspect also provides an improvement of the awareness of the cross-curricular links. By realizing the relationship between state/government, academia, market and industry and making science more relatable to everyday life, this framework is more representative of real life. If the aim is to teach how science operates in society, this framework helps students to see the everyday applications of science and the operation of the scientific process from academia to the market rather than only focusing on how science operates within academia. In addition, due to the inclusion of the scientific ethos and social values of science, this framework also integrates an "ethical dimension" to our understanding. Due to its inclusion of all elements of 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.

Secondly, the SAMI cycle framework can benefit the economy and society due to its possible impact on students' understanding. The inclusion of EOS and entrepreneurship in the SAMI cycle framework contributes to increasing students' awareness of self-employment as a career option and the possibility of starting their own business. Thus, improving the awareness of students on current issues like social and economic issues in NOS and science education can have a high impact on the economic well-being of a nation (Kelly 2007). Furthermore, entrepreneurship has an important role in the social and economic development of countries (Etzkowitz 2008). For instance, there are opportunities in the USA, to apply for federally sponsored research by the National Science Foundation 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). 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 National Science Education Standards (National Research Council 1996) recommend that students must have the opportunity to experience science authentically and free of misconceptions and idealizations about the nature of the scientific enterprise. Within this context, learning about the nature of scientific enterprise may contribute to developing responsible citizens who are sensitive about scientific issues (Erduran and Dagher 2014; Erduran and Mugaloglu 2013).

We believe that due to the pertinence of how science operates in society, EOS and entrepreneurship to NOS and science education, the SAMI cycle framework is of relevance to NOS and science education. By proposing this framework, we support the development of more authentic and engaging science classes as well as an improvement in the students' and teachers' interpretation of social aspects of NOS, cross-curricular links between different subjects, and of how science actually operates in society. Within this context, the ways of enabling this conceptualization for classroom practice should also be considered. Therefore, in the next section, we discuss some of the possible implications of the contemporary aspects of NOS and the SAMI cycle framework.

7 Implications for Science Education

In this section, the possible implications of the contemporary aspects of NOS and the SAMI cycle framework are discussed to enrich its practical applications. Within this purpose, there are some aspects considered to teach the social aspects of NOS and the SAMI cycle framework:

- Integration into the syllabus
- Integration into teacher education
- Integration into classroom teaching

Concerning the integration into the curriculum, economics and entrepreneurship are among the most coveted skills in education in many countries. For example, there is a reference to the entrepreneurial skills and economics in the 24 statements of learning in the Irish Framework for Junior Cycle (DES 2004, 2015). Ireland is not alone considering the integration of economics of science and entrepreneurship into education. For example, in the Turkish Science Curriculum (Board of Education and Discipline 2013), entrepreneurship is referred to as one of the life skills and the importance of economics has been emphasized. There are some other countries, such as the US, Sweden and Finland, highlighting 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). Although many countries such as the US and Ireland have a focus on NOS in their syllabi, 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). The syllabus dictates what teachers teach in the classroom. Thus, how and where the social aspects of NOS and the SAMI cycle framework can be integrated into the curriculum are of importance. In Ireland, ‘Science in Society’ is one of the NOS strands in the Junior Cycle Specification (DES 2015) and this strand has the potential to embrace the social aspects of NOS and the SAMI cycle framework.

When there is a topic in the curriculum, teachers should be able to apply it in the classroom. If teachers do not understand the topic, it cannot be applied in the classroom effectively. Therefore, integration into teacher education is of importance in order to make teachers feel knowledgeable about a topic. Teacher education is mainly concerned with equipping teachers with knowledge, skills, and attitudes (European Commission 2008, 2012) to perform their role in the classroom, school, and community efficiently based on contemporary policies, procedures, and provision. Conway et al. (2009, p.6) highlighted the importance of locating “teacher education in its socio-cultural contexts including political, cultural, economic, emotional and moral dimensions”. Different techniques can be used to implement social aspects of NOS and the SAMI cycle framework into teacher education, such as argumentation, group discussion, role-play, think-pair-share, concept statement and online learning. Once a topic is included in the syllabus, and teacher education programs have prepared them to teach such topics, it can be integrated into the classroom. The same techniques and more can also be used to implement social aspects of NOS and the SAMI cycle into second-level education. Some examples are provided here to exemplify the implications of EOS, entrepreneurship, and the SAMI cycle framework in classroom practice. For example, a concept statement activity can be used to teach biotechnology to PSTs by integrating entrepreneurship and EOS into NOS and discussing the role of the SAMI cycle. The concept statement is commonly used in business schools or business departments, and it is an overview of a business plan, which is a new product or service proposal. A brief example activity is provided in Fig. 4.

This concept statement activity can play a role as a project assignment for different science subjects. Although Fig. 4 is a group activity, it can also be used as an individual project assignment.

Furthermore, this activity can also be conducted without utilizing a specific topic. Likewise, argumentation can be used to teach biotechnology in the context of EOS. For example, Erduran and Mugaloglu (2013) developed an activity, in which the economic dimensions of the GMO related issues were highlighted by using the argumentation technique aimed at second-level education, which includes students aged 12–18 approximately. In this activity, two claims and some evidence statements are given to students. These evidence statements are used to help build up each claim or to refute the alternative claim. These example activities can be used to implement social aspects of NOS and the SAMI cycle into both teacher education and second-level schools, once the difficulty is adjusted according to the age. Some other educational applications might include discussing different social aspects of NOS, such as scientific ethos, EOS, and entrepreneurship at second- and third-level education based on the discovery of the Haber-Bosch process in Perutz (2002). Even a specific aspect of EOS such as *funding of research at academic institutions* might be argued based on a scientist who receives an NIH grant to offer students an example of how science works in society in second- and third-level education. Likewise, the economics and entrepreneurship behind the chickenpox vaccination can be brought up in the classroom.

As demonstrated in the earlier sections, the social aspects of NOS and the SAMI cycle framework can be applied together 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.

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

Fig. 4 Concept Statement Activity

8 Conclusions

In this article, we have argued that the SIS of science should be revisited and reconsidered through the perspectives of contemporary aspects of science, such as EOS and entrepreneurship to enhance the depth and breadth of the SIS of science in NOS. Therefore, we proposed to change financial Systems in NOS to "contemporary aspects of NOS" and include EOS and entrepreneurship as contemporary aspects of science. Within this context, each of these two aspects was also extended and re-structured. We also re-defined entrepreneurship in the NOS context. Furthermore, we proposed a framework—the SAMI cycle framework—which is the illustration and approximation of how science works in society. The SAMI cycle framework aims to provide a coherent overarching framework to conceptualize all social aspects of NOS including EOS and entrepreneurship and the relationship between these aspects. We also investigated the educational applications of the social aspects of NOS and the SAMI cycle framework in the curriculum, teacher education and classroom (second and third-level education).

It is worth emphasizing that integrating entrepreneurship and EOS into NOS by highlighting their relevance to each other could make many contributions to science education literature. For example, this integration can contribute to developing an effective process of the operation of science as a SIS holistically. Moreover, this integration can support students to develop a greater understanding of cross-curricular links, which can assist them in contextualizing how science works in society. Furthermore, the SAMI cycle framework provides a practical and visual tool which could help enhance not only the comprehensive understanding of how science works in society, but also students' awareness of the relevance between state, science, industry, and the market. By performing this integration, we support the development of more authentic and engaging science classes as well as the improvement in the students' interpretation of the relationship between science and society. In this research, we focus on physics, chemistry, and biology since they are the main science fields taught in science education. Further research may be conducted to adapt this cycle and its activity to different sciences to unveil their social-institutional side. In conclusion, awareness of the association between EOS, entrepreneurship, NOS, and science education is likely to aid in the development of responsible citizens with a sound understanding of science in its broader socio-economic context (Sanders 2007; Kelly 2007) and to enthuse students about science.

Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

References

Abd-El-Khalick, F. (2012). Teaching with and about nature of science, and science teacher knowledge domains. *Science & Education, 22*(9), 2087–2107.

Achor, E. E., & Wilfred-Bonse, U. K. (2013). The need to integrate entrepreneurship education into science education teachers' curriculum in Nigeria. *Journal of Science and Vocational Education, 7*, 111–123.

Adeyemo, S. A. (2009). Understanding and acquisition of entrepreneurial skills: a pedagogical re-orientation for classroom teacher in science education. *Journal of Turkish Science Education, 6*(3), 57–65.

Allchin, D. (2011). Evaluating knowledge of the nature of (whole) science. *Science Education, 95*(3), 518–542.

Allchin, D., Andersen, H. M., & Nielsen, K. (2014). Complementary approaches to teaching nature of science: Integrating student inquiry, historical cases, and contemporary cases in classroom practice. *Science Education, 98*(3), 461–486.
Allen, K. R. (2003). *Bringing new technology to market*. Upper Saddle River: Prentice Hall.
Amos, A. A., & Onifade, C. A. (2013). The perception of students on the need for entrepreneurship education in teacher education programme. *Global Journal of Human Social Science, 13*(3), 75–80.
Annetta, L., Shapiro, M., & Lamb, R. (2017, April). Entrepreneurial thinking: Cross-cutting concepts for science teachers. Paper presented at *NARST 90th Annual International Conference,* San Antonio, USA.
Armstrong, P., & Tomes, A. (2010). Entrepreneurship in science: case studies from liquid crystal application. *Prometheus, 18*(2), 133–147.
Audretsch, D. B., Bozeman, B., Combs, K. L., Feldman, M., Link, A. N., Siegel, D. S., et al. (2002). The economics of science and technology. *The Journal of Technology Transfer, 27*(2), 155–203.
Bacanak, A. (2013). Teachers' views about science and technology lesson effects on the development of students' entrepreneurship skills. *Educational Sciences: Theory and Practice, 13*(1), 622–629.
Bikse, V., & Riemere, I. (2013). The development of entrepreneurial competences for students of mathematics and the science subjects: The Latvian experience. *Procedia - Social and Behavioral Sciences, 82*, 511–519.
Bird, B. J., Hayward, D. J., & Allen, D. N. (1993). Conflicts in the commercialization of knowledge: perspectives from science and entrepreneurship. *Entrepreneurship: Theory and Practice, 17*(4), 57–78.
Birdthistle, N. (2004). Small family businesses as learning Organisations: an Irish study, unpublished thesis (doctoral thesis), University of Limerick.
Birdthistle, N., Hynes, B., & Fleming, P. (2007). Enterprise education programmes in secondary schools in Ireland: a multi-stakeholder perspective. *Education+ Training Journal, 49*(4), 265–276.
Black, J., Hashimzade, N., & Myles, G. (2009). *A dictionary of economics*. Oxford: Oxford University Press.
Board of Education and Discipline (2013). *Turkish science curriculum*. Ankara: Board of Education and Discipline.
Brown, W. (2003). Neo-liberalism and the end of liberal democracy. *Theory & Event, 7*(1), Johns Hopkins University Press. Retrieved August 6, 2018, from Project MUSE database.
Bruyat, C., & Julien, P. A. (2001). Defining the field of research in entrepreneurship. *Journal of Business Venturing, 16*(2), 165–180.
Buang, N. A., Halim, L., & Meerah, T. S. M. (2009). Understanding the thinking of scientists entrepreneurs: Implications for science education in Malaysia. *Journal of Turkish Science Education, 6*(2), 3–11.
Carter, L. (2008). Globalization and science education: the implications of science in the new economy. *Journal of Research in Science Teaching, 45*(5), 617–633.
Conway, P., Murphy, R., Rath, A., & Hall, K. (2009). *Learning to teach and its implications for the continuum of teacher education: a nine-country cross-national study*. Maynooth: The Teaching Council.
DES (Department of Education and Skills). (2004). *A brief description of the Irish education system* (pp. 1–36). Dublin: Communications Unit Department of Education and Science.
DES (Department of Education and Skills) (2015). *Junior Cycle Science Curriculum Specification*. (pp. 1–26). Dublin: Communications Unit Department of Education and Science.
Deveci, I. (2016). Perceptions and competence of Turkish pre-service science teachers with regard to entrepreneurship. *Australian Journal of Teacher Education, 41*(5), 153–170.
Deveci, I., & Cepni, S. (2014). Entrepreneurship in science teacher education. *Journal of Turkish Science Education, 11*(2), 161–188.
Deveci, I., & Seikkula-Leino, J. (2016). Finnish science teacher educators' opinions about the implementation process related to entrepreneurship education. *Electronic Journal of Science Education, 20*(4), 1–20.
Diamond, A. M. J. (2008). Economics of science. *The New Palgrave Dictionary of Economics, 7*, 1–27.
Driver, R., Leach, J., & Millar, R. (1996). *Young people's images of science*. Buckingham: Open University Press.
Ejilibe, O. C. (2012). Entrepreneurship in biology education as a means for employment. *Knowledge Review, 26*(3), 96–100.
Erduran, S. (2014). Beyond nature of science: The case for reconceptualising 'science' for science education. *Science Education International, 25*(1), 93–111.
Erduran, S., & Dagher, Z. R. (2014). *Reconceptualizing the nature of science for science education: scientific knowledge, practices and other family categories*. Dordrecht: Springer.
Erduran, S., & Mugaloglu, E. Z. (2013). Interactions of economics of science and science education: Investigating the implications for science teaching and learning. *Science & Education, 22*(10), 2405–2425.
Etzkowitz, H. (2008). *The triple helix: University-industry-government innovation in action*. New York: Routledge.
Etzkowitz, H., & Leydesdorff, L. (1998). The endless transition: a "triple helix" of university-industry-government relations. *Minerva, 36*(3), 203–208.

European Commission. (2004). *Education for entrepreneurship: making progress in promoting entrepreneurial attitudes and skills through primary and secondary education*. Brussels: European Commission.

European Commission. (2008). *Entrepreneurship in higher education, especially in non-business studies*. Brussels: European Commission.

European Commission. (2012). *Entrepreneurship education at school in Europe: national strategies, curricula and learning outcomes*. Brussels: European Commission.

Ezeudu, F. O., Ofoegbu, T. O., & Anyaegbunnam, N. J. (2013). Restructuring STM (science, technology, and mathematics) education for entrepreneurship. *US-China Education Review A, 3*(1), 27–32.

Foucault, M., Davidson, A. I., & Burchell, G. (2008). *The birth of biopolitics: lectures at the Collège de France, 1978–1979*. Basingstoke: Palgrave Macmillan.

Hisrich, R. D., & Peters, M. P. (2002). *Entrepreneurship*. New Delhi: McGraw-Hill.

Hoselitz, B. F. (1952). Entrepreneurship and economic growth. *American Journal of Economics and Sociology, 12*(1), 97–111.

Hynes, B., Costin, Y., & Birdthistle, N. (2010). 'Practice-based learning in entrepreneurship education: A means of connecting knowledge producers and users', higher education. *Skills and Work-based Learning, 1*(1), 16–28.

Irzik, G. (2007). Commercialization of science in a neoliberal world. In *Reading Karl Polanyi for the twenty-first century* (pp. 135–153). New York: Palgrave Macmillan.

Irzik, G. (2013). Introduction: Commercialization of academic science and a new agenda for science education. *Science & Education, 22*(10), 2375–2384.

Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & Education, 20*(7), 591–607.

Irzik, G., & Nola, R. (2014). New directions for nature of science research. In *International handbook of research in history, philosophy and science teaching* (pp. 999–1021). Dordrecht: Springer.

Jiang, H., Xiong, W., & Cao, Y. (2017). Research on the mechanism of entrepreneurial education quality, entrepreneurial self-efficacy and entrepreneurial intention in social sciences, engineering and science education. *EURASIA Journal of Mathematics, Science and Technology Education, 13*(7), 3709–3721.

Jiménez-Aleixandre, M. P. (2015). Reconceptualizing the nature of science. *Science & Education, 24*(9–10), 1241–1244.

Johnston, R. F., & Edwards, C. G. (1987). *Entrepreneurial science: new links between corporations, universities, and government*. New York: Forum Books.

Johson, K., & Amiraly, A. (2017). Bringing entrepreneurial methods into the scientific classroom: A case study of action learning at Ecole polytechnique. *HAL, 486*(3), 1–15.

Kaya, S., Birdthistle, N. and Erduran, S. (2018). From traditional to contemporary aspects of NOS: Trainee science teachers' perceptions on economics and entrepreneurship, in National Association for Research in Science Teaching (NARST): 2018 Annual International Conference, Atlanta, GA, United States, 10–13 March.

Kelly, G. (2007). Scientific literacy, discourse, and knowledge. In Linnaeus Tercentenary Symposium, Upsala, Sweden (pp. 47-55).

Kleppe, J. A. (2002). Teaching invention, innovation, and entrepreneurship to Northern Nevada high school science and math teachers. *IEEE Antennas and Propagation Magazine, 44*(5), 115–119.

Krimsky, S. (2004). *Science in the private interest: Has the lure of profits corrupted biomedical research*?. Lanham: Rowman-Littlefield Publishing.

Lederman, N. G., Abd-El-Khalick, F., Bell, R. L., & Schwartz, R. S. (2002). Views of nature of science questionnaire: Toward valid and meaningful assessment of learners' conceptions of nature of science. *Journal of Research in Science Teaching, 39*(6), 497–521.

Lee, H., Chang, H., Choi, K., Kim, S.-W., & Zeidler, D. L. (2012). Developing character and values for global citizens: analysis of pre-service science teachers' moral reasoning on socioscientific issues. *International Journal of Science Education, 34*(6), 925–953.

Lepistö, J., & Ronkko, M. L. (2013). Teacher students as future entrepreneurship educators and learning facilitators. *Education + Training Journal, 55*(7), 641–653.

Maci, S. (2017). Per-Simon Kildal: Friend, scientist, educator, entrepreneur. In *11th European Conference on Antennas and Propagation (EUCAP), Paris,* (pp. 215–219).

Martin, A. M., Abd-El-Khalick, F., Mustari, E., & Price, R. (2017). Effectual reasoning and innovation among entrepreneurial science teacher leaders: a correlational study. *Research in Science Education, 1*, 1–23.

Martins, A. F. P., & Ryder, J. (2015). Nature of science in science education: A proposal based on 'themes'. In *GIREP-MPTL International Conference on Teaching/Learning Physics, Poland*.

Matthews, M. R. (2012). Changing the focus: From nature of science (NOS) to features of science (FOS). In M. S. Khine (Ed.), *Advances in nature of science research* (pp. 3–26). Dordrecht: Springer.

Matthews, M. R. (2014). *Science teaching: The contribution of history and philosophy of science*. New York: Routledge.

McComas, W. F., Clough, M. P., & Almazroa, H. (1998). The role and character of the nature of science in science education. In W. F. McComas (Ed.), *The nature of science in science education* (pp. 3–39). Dordrecht: Springer.

Mirowski, P., & Sent, E. M. (2002). *Science bought and sold: Essays in the economics of science*. Chicago: University of Chicago Press.

Mirowski, P., & Sent, E. M. (2008). The commercialization of science, and the response of STS*. In E. J. Hackett, O. Amsterdamska, M. Lynch, J. Wajcmanet al. (Eds.), *Handbook of science and technology studies* (pp. 635-689). Cambridge: MIT Press.

Mueller, P. (2006). Exploring the knowledge filter: how entrepreneurship and university-industry relationships drive economic growth. *Research Policy, 35*(10), 1499–1508.

National Research Council. (1996). *National science education standards*. Washington, DC: National Academies Press.

Nwakaego, O. N., & Kabiru, A. M. (2015). The need to incorporate entrepreneurship education into chemistry curriculum for colleges of education in Nigeria. *Journal of Educational Policy and Entrepreneurial Research, 2*(5), 84–90.

Oliver, A. L. (2004). Biotechnology entrepreneurial scientists and their collaborations. *Research Policy, 33*(4), 583–597.

Pedretti, E., & Nazir, J. (2011). Currents in STSE education: mapping a complex field, 40 years on. *Science Education, 95*(4), 601–626.

Perutz, M. F. (2002). *I wish I'd made you angry earlier: essays on science, scientists, and humanity*. USA: Oxford University press.

Polanyi, K. (1957). *The great transformation: The political and economic origin of our time*. Beacon Hill: Beacon Press.

Radder, H. (2010). *The commodification of academic research: analyses, assessment, alternatives*. Pittsburgh: University of Pittsburg Press.

Resnik, D. B., & Elliott, K. C. (2013). Taking financial relationships into account when assessing research. *Accountability in Research, 20*(3), 184–205.

Rindova, V., Barry, D., & Ketchen, D. J. (2009). Entrepreneuring as emancipation. *Academy of Management Review, 34*(3), 477–491.

Romer, P. M. (2001). Should the government subsidize supply or demand in the market for scientists and engineers? In A. B. Jaffe, J. Lerner, & S. Stern (Eds.), *Innovation policy and the economy* (pp. 221–252, Vol. 1). Cambridge: MIT press.

Sadler, T. D., & Dawson, V. (2012). Socio-scientific issues in science education: Contexts for the promotion of key learning outcomes. In B. J. Fraser, K. Tobin, & C. J. McRobbie (Eds.), *Second international handbook of science education* (pp. 799–809). Dordrecht: Springer Netherlands.

Sanders, M. (2007). Scientific paradigms, entrepreneurial opportunities and cycles in economic growth. *Small Business Economics, 28*(4), 339–354.

Sarasvathy, S. D., & Venkataraman, S. (2011). Entrepreneurship as method: open questions for an entrepreneurial future. *Entrepreneurship Theory and Practice, 35*(1), 113–135.

Schumpeter, J. (1934). *Capitalism, socialism, and democracy*. New York: Harper & Row.

Shane, S., & Venkataraman, S. (2000). The promise of entrepreneurship as a field of research. *Academy of Management Review, 25*(1), 217–226.

Shapero, A. (1975). The displaced, uncomfortable entrepreneur. *Psychology Today, 9*(6), 83–88.

Stephan, P. E. (1996). Economics of science. *Journal of Economic Literature, 34*(3), 1199–1235.

The Entrepreneurial School (2014-2015). A project for teachers by teachers: the entrepreneurial school. http://entrepreneurialschool.eu/the-entrepreneurial-school. Accessed 16 June 2016.

Timmons, J. A. (1989). *The entrepreneurial mind*. Andover: Brick House Publishing.