International Journal of Science Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tsed20

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To cite this article: Martina Caramaschi, Alison Cullinane, Olivia Levrini & Sibel Erduran (2021): Mapping the nature of science in the Italian physics curriculum: from missing links to opportunities for reform, International Journal of Science Education, DOI: 10.1080/09500693.2021.2017061

To link to this article: https://doi.org/10.1080/09500693.2021.2017061

Published online: 31 Dec 2021.

INTERNATIONAL JOURNAL OF SCIENCE EDUCATION
https://doi.org/10.1080/09500693.2021.2017061

Mapping the nature of science in the Italian physics curriculum: from missing links to opportunities for reform

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ABSTRACT

The article describes the analysis of the Italian physics curriculum documents in terms of the coverage of nature of science (NOS). NOS is not explicitly presented as part of the Italian high-school physics curriculum. The article focuses on analysing the implicit aspects of the curriculum documents. The Family Resemblance Approach (FRA) to NOS was used as an analytical lens. FRA was chosen because of the broad range of categories that it provides to trace curriculum content. Curriculum documents were analysed using the FRA categories as well as an Epistemic Network Analysis (ENA) which has shown important limitations in the FRA categories 'Political Power Structures, Scientific Ethos, Professional Activities'. These aspects of NOS belong to the social-institutional aspects of the FRA framework. There were also some inconsistencies between the general section and the specific sections of the curriculum. The study elaborates on how FRA and ENA can be used to analyse NOS content in a science curriculum. The epistemic networks provide concrete illustrations of where curriculum revision can best be carried out to promote underrepresented aspects of NOS. Implications for future research and recommendations for curriculum reform internationally are suggested.

ARTICLE HISTORY
Received 5 December 2020
Accepted 7 December 2021

KEYWORDS
Nature of science; curriculum; Italian science education

Introduction

The concept of the curriculum is very old and its meaning has changed over the years in how we theorise and understand it. Curriculum knowledge is knowledge of what should be taught to a particular group of pupils to guarantee an equal and comparable education to students attending different schools in a country. Curriculum includes benchmarks, learning goals, but also knowledge of the variation in instructional material available and knowledge of the reasons why you would or would not use particular material in certain circumstances (Ball et al., 2008; Shulman, 1986). Modern concepts of educational curriculums tend to combine two purposes. One purpose is on the process of individual cognitive development and the other on the process of socialisation and how one adjusts

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or attributes to society and social environments. NOS-rich curricula that guide teaching and assessment by encouraging teachers to include this content in the classroom will play an important part in developing the individual and socialisation processes (McComas & Nouri, 2016). The Italian physics curriculum document that will be analysed in this paper is the official document that schools have to consider to guarantee uniformity in the contents and in the learning outcomes over the country. As we will explain later, the document is written to allow freedom for the teachers to make their pedagogical choices.

The analysis of the curriculum was guided by a particular framework of NOS called the expanded Family Resemblance Approach (FRA) (Irzik & Nola, 2014). The FRA framework refers to NOS as a cognitive-epistemic and social-institutional system (Erduran & Dagher, 2014a). Although the framework is broad, it focuses on, among other factors, the cognitive development and social aspects of science. It is primed for investigating modern curriculum and it provides a useful organisational framework for analysing science curriculum and instruction and gives rise to a richer understanding of and about science. The curriculum is incredibly important for the enactment of science content knowledge, and it is one of the defining features of teacher knowledge bases (Shulman, 1986). Since the curriculum document has no explicit NOS section, the implicit NOS elements were analysed for NOS opportunities. The article provides details for teachers and curriculum developers on how NOS can be made explicit and investigates how the connections between the categories in the content can be made for teaching NOS. The aim is to aid understanding of the curriculum to show how the categories in the FRA framework are connected by using an Epistemic Network Analysis (ENA) and help visualise the type and frequency of connections between categories in the curriculum (Shaffer et al., 2016).

Nature of science and physics education

The term 'Nature of Science' (NOS) has been defined in numerous ways over the years and often is used by science educators to discuss matters such as what is science, how it functions, the epistemological and ontological foundations of science, how scientists act as a social group and how society influences and reacts to scientific activities (Clough & Olson, 2008). Lederman (1992) refers to the NOS as the values and assumptions fundamental to science and its knowledge development, which include independence of thought, creativity, tentativeness, empirically based, subjectivity, testability and cultural and social embeddedness. McComas (2003) refers to the definition and scope of NOS as the 'rules of the game' (p. 25) which have led to the knowledge production and the evaluation of truth claims in the natural world. Similar to Clough and Olson (2008), his definition states that NOS includes learning about how science functions, viewing scientists at work and reviewing their interactions in a community. The nature of science (NOS) has become a major field of research in science education over the last several decades, and this is proven by the prolific body of publications in this area (Rubba & Anderson, 1978; Lederman, 1992; Driver et al., 1996; Alters, 1997; Abd-El-Khalick et al., 1998; McComas et al., 1998; Erduran & Kaya, 2019; Galili, 2019; Hodson, 1988). As early as the 1960s, attention was paid to the NOS as it was seen to be a key component of scientific literacy. Attention supporting an understanding of science from philosophical and historical perspectives has been spotlighted worldwide, where it is now an explicit goal in science curricula (Olson, 2018). Although it is the goal to teach the nature of science, the question is still being asked; whose version is to be taught? And useful pedagogical frameworks of NOS from history and philosophy of science in science education are currently sparse.

For the last 30 years, the science education community has largely focused on a perspective commonly referred to as the 'consensus view' (Lederman et al., 2002). As such, the view holds a special place in the history of NOS research, as the framework was used in bodies of NOS related work at all educational levels and appreciated, mainly, for its inner consistency and coherence. It presents itself as a set of tenets deemed appropriate for science K-12 instruction and includes ideas such as (1) Tentativeness of Scientific Knowledge, (2) Observations and Inferences, (3) Subjectivity and Objectivity in Science, (4) Creativity and Rationality, (5) Social and Cultural Embeddedness in Science, (6) Scientific Theories and Laws and (7) Scientific Methods. As more ideas and frameworks emerge, criticisms have been made of the approach. Those in favour of this NOS view have responded to its critics by stating that the tenets were never intended to be taught as declarative statements, but are summative statements for much deeper ideas, and the problem lies with the pedagogy and teacher professional development, rather with the model itself (Lederman & Lederman, 2014). Nevertheless, critics insist that the tenets oversimplify NOS to the extent that they significantly misrepresent NOS (Hodson & Wong, 2017). Yacoubian (2012) and Hodson and Wong (2017) detail how the consensus view presents a narrow focus and does not provide direction for applying NOS ideas to various ends, distorts the elementary core of NOS and does not offer a developmental trajectory for teaching NOS content. Other critics have produced frameworks they feel are more authentic representations of NOS that are inclusive and diverse and provided more guidance for science educational needs on how to apply NOS ideas in various ways, some of which will be discussed in this paper.

Physics as a subject is well primed to include the history and philosophy of science which are concepts that fall under the umbrella of NOS. The subject naturally evokes philosophical questions, that students can be guided to address to reflect on the historical changes in knowledge systems, and in the development of the epistemic ways that have progressively been used to test, share, value and accept pieces of knowledge as 'true' (Stadermann & Goedhart, 2020; Levrini et al., 2014). Physics content progression in history has often represented for Physics Education Research an interesting source of knowledge to investigate possible corresponding parallels between the evolving idea in learning and the historical development of physics as a discipline (Matthews, 1994). Despite these epistemological and philosophical foundations of physics, their relevance is usually not emphasised in science curricula and ultimately not in the secondary physics classrooms (Stadermann & Goedhart, 2020). This lack of emphasis is largely the responsibility of curricular documents. Looking at curricula, they are little more than a collection of concepts. Curricular documents are often used as foundations for textbook designers, which research has shown often miss opportunities to present historical and contemporary vignettes from curriculum content (McDonald & Abd-El-Khalick, 2017). This has a cause and effect for classroom practice as teachers heavily rely on textbooks to design and deliver their lesson content. Therefore, policymakers need to take better considerations and make it an important goal for curricular documents to emphasise NOS.

Research has shown that providing perspectives of NOS from physics does indeed allow for debate and intrigue, thus making it much more appealing to the students (Lederman, 2006; Lederman & Lederman, 2014). Science education literature from the last 30 years has recognised the importance of history and philosophy of science (Hodson, 1988; Monk & Osborne, 1997; Niaz, 1998; Levrini & Fantini, 2013), and so the decision to include the history of physics in science curricula should not be a dilemma, but yet often they fall short of explicit instruction and cognitive learning goals for teachers (Olson, 2018; Yeh et al., 2019). One of the early counties to include it in its curriculum policy documents was the USA with the publication of Science for all Americans (AAAS, 1989) and the Science Education Content Standards (NRC, 1996). Addressing the nature and history of science thus became an important science education content standard that was expected to support content standards in the physical, earth and life sciences, alongside a focus on inquiry and technological design (Erduran & Dagher, 2014b). Recently other countries have seen the explicit inclusion of NOS in its curricular documents (i.e. New Zealand, Ireland). The Italian science curricula do not have explicit sections designated to the NOS. The article describes how the analysis of the Italian physics curriculum (MIUR, 2010a) was undertaken to illustrate where NOS could be explicitly taught. As NOS is not explicitly taught as part of the Italian physics curriculum, the focus lays on analysing the implicit aspects to investigate how NOS is positioned. The Family Resemblance Approach (FRA) framework (Erduran & Dagher, 2014a) guided the analysis of the documents. This model was chosen as it is an emerging area of NOS literature that is showing to have an impact on how nature of science is now being researched (Erduran & Kaya, 2019; MacDonald, 2017; McDonald & Abd-El-Khalick, 2017; Yeh et al., 2019).

Family Resemblance Approach to nature of science

To investigate how NOS is present in the Italian Physics curriculum, we adopted the FRA vision of NOS. The family resemblance concept originated in Wittgenstein's work and it was applied to the characterisation of NOS by Irzik and Nola (2014) as well as Erduran and Dagher (2014a). The framework was theorised by Irzik and Nola (2011) and reconceptualised for science education by Erduran and Dagher (2014a).

The approach takes a specific stance with respect to the delicate methodological problem of defining science, accounting both for the diversity of the scientific disciplines and their reciprocal resemblances that create the 'science family'. The approach assumes that 'there is no fixed set of necessary and sufficient conditions which determine the meaning of [science]' (Irzik & Nola, 2011, p. 594). Yet, just like in a family, each member (out of the metaphor, each discipline) resembles some family members with respect to some aspects and other members with respect to other aspects. The core of the FRA approach applied to NOS is the individuation of the clusters of the aspects that can be used to compare the disciplines and, as a whole, to characterise the Nature of Science.

This framework is presented in Table 1 and was used for the analysis along with the FRA wheel (Erduran & Dagher, 2014a, p. 28). It represents the Nature of Science as a system with cognitive-epistemic and social-institutional aspects. This holistic representation of NOS is composed of 11 categories, across the 2 aspects which constantly interact with each other in numerous ways (Irzik & Nola, 2014). Science as a cognitive-epistemic system encompasses processes of inquiry, aims and values, methods and methodological

Table 1. FRA categories Erduran and Dagher (2014a).

Cognitive-epistemic aspects	Aims and values	The scientific enterprise is underpinned by adherence to a set of values that guide scientific practices. These aims and values are often implicit and they may include accuracy, objectivity, consistency, scepticism, rationality, simplicity, empirical adequacy, prediction, testability, novelty, fruitfulness, commitment to logic, viability, and explanatory power.
	Scientific Practices	The scientific enterprise encompasses a wide range of cognitive, epistemic, and discursive practices. Scientific practices such as observation, classification, and experimentation utilise a variety of methods to gather observational, historical, or experimental data. Cognitive practices, such as explaining, modelling, and predicting, are closely linked to discursive practices involving argumentation and reasoning.
	Methods and methodological rules	Scientists engage in disciplined inquiry by utilising a variety of observational, investigative, and analytical methods to generate reliable evidence and construct theories, laws, and models in a given science discipline, which are guided by particular methodological rules. Scientific methods are revisionary in nature, with different methods producing different forms of evidence, leading to clearer understandings and more coherent explanations of scientific phenomena.
	Scientific knowledge	Theories, laws, and models (TLM) are interrelated products of the scientific enterprise that generate and/or validate scientific knowledge and provide logical and consistent explanations to develop scientific understanding. Scientific knowledge is holistic and relational, and TLM are conceptualised as a coherent network, not as discrete and disconnected fragments of knowledge.
Social-Institutional aspects	Professional activities	Scientists engage in a number of professional activities to enable them to communicate their research, including conference attendance and presentation, writing manuscripts for peer-reviewed journals, reviewing papers, developing grant proposals, and securing funding.
	Scientific ethos	Scientists are expected to abide by a set of norms both within their own work and during their interactions with colleagues and scientists from other institutions. These norms may include organised scepticism, universalism, communalism and disinterestedness, freedom and openness, intellectual honesty, respect for research subjects, and respect for the environment.
	Social certification and dissemination	By presenting their work at conferences and writing manuscripts for peer-reviewed journals, scientists' work is reviewed and critically evaluated by their peers. This form of social quality control aids in the validation of new scientific knowledge by the broader scientific community.
	Social values of science	The scientific enterprise embodies various social values including social utility, respecting the environment, freedom, decentralising power, honesty, addressing human needs, and equality of intellectual authority.
	Social organisations and interactions	Science is socially organised in various institutions including universities and research centres. The nature of social interactions among members of a research team working on different projects is governed by an organisational hierarchy. In a wider organisational context, the institute of science has been linked to industry and the defence force.
	Political power structures	The scientific enterprise operates within a political environment that imposes its own values and interests. Science is not universal, and the outcomes of science are not always beneficial for individuals, groups, communities, or cultures.
	Financial systems	The scientific enterprise is mediated by economic factors. Scientists require funding in order to carry out their work, and state- and national-level governing bodies provide significant levels of funding to universities and research centres. As such, these organisations have an influence on the types of scientific research funded, and ultimately conducted.

rules, and scientific knowledge, while science as a social-institutional system encompasses professional activities, scientific ethos, social certification and dissemination of scientific knowledge, and social values. Figure 1 presents the FRA wheel designed by Erduran and Dagher (2014a, p. 28).

Since its inception, the FRA model has been used in science education to develop strategies inteacher education (Cullinane, 2018; Erduran et al., 2021; Erduran & Kaya, 2018, 2019) and as a tool for conceptualising research and innovation policies in education (Laherto et al., 2018) and document analysis of curricula and textbooks (Kaya & Erduran, 2016; McDonald, 2017; Park, Seungran Yang, et al., 2020; Park, Wu, et al., 2020; Yeh et al., 2019). The framework has recently been used in geography education to categorise the implicit structure of the discipline in order to develop the nature of geography for teacher educators (Puttick & Cullinane, 2021). The affordance of the FRA framework for investigating students' views of nature of science at university level has been investigated (Akgun & Kaya, 2020) and FRA has been suggested as a useful framework to develop university students' identities as scientists (Mohan & Kelly, 2020). Within the European IDENTITIES project (www.identities.eu) the framework is used to elaborate on the concept of 'discipline', within the broader problem to define interdisciplinarity (Alvargonzález, 2011). As the Latin root 'discere' (to learn) reminds, a 'discipline' is a re-organisation of knowledge with the scope of teaching it. Disciplines ground their roots into the educational necessity to re-organise knowledge in such a way that students, whilst building their knowledge, can also develop epistemic skills, such as problem solving, modelling, representing, arguing, explaining, testing, sharing and so on. The IDENTITIES project is using the FRA framework to compare the epistemic core of the different S-T-E-M disciplines and reflect on their identities in terms of confront between their values/aims, practices, methods and ways to organise knowledge (Branchetti & Levrini, 2021).

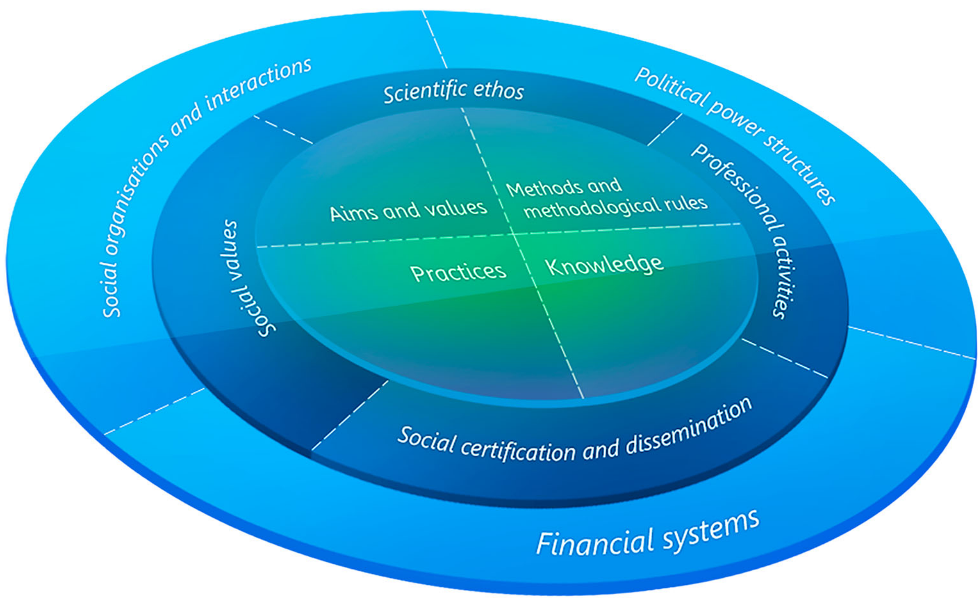

Figure 1. FRA wheel: science as a cognitive-epistemic and social-institutional system (Erduran & Dagher, 2014a, p. 28).

We have chosen to use FRA as an analytical framework because it is fairly broad and inclusive of different aspects of NOS. Our aim was to investigate the extent to which the Italian curriculum documents refer to different aspects of NOS so other characterisations of NOS that focus on a particular set of statements (e.g. Lederman et al., 2002) would not have been fit for this purpose. Furthermore, the FRA inherently highlights the interconnectedness of ideas about NOS and we wanted to explore how the different FRA categories were related to each other in the curriculum standards. In their publication, A clear description of each FRA frameworkcategory of the wheel (Figure 1) is expanded on and adapted in Table 1. This revised version also aided in the analytical process of the curriculum documents reported in this study, as it was consulted often when there was any debate or discrepancy in the classification process.

Secondary schooling and science curricula in Italy

In order to be able to draw some international comparisons, a brief overview of the organisational structure of the Secondary schooling in Italy is reported. In Italy, there are three types of high schools, that are *Liceo*, *Istituto Tecnico* and *Istituto Professionale*. *Liceo* provides cultural and methodological instruments to have a deep understanding of reality and develops logic, creative, rational and critical approaches to situations. There exist six different types of *Liceo*, depending on the discipline focus. One of those is scientific lyceum high school *(Liceo Scientifico*), in which several hours are dedicated to teaching scientific disciplines like Mathematics, Physics, Biology, and Chemistry, along with basic cultural disciplines such as Italian, Latin, Philosophy, Art and History. The other two types of high schools – *Istituto Tecnico* and *Istituto Professionale* – offer technical and vocational training (MIUR, 2018), but it is reductive to describe them in a nutshell. However, in all the high school types in Italy, students study physics, for at least one year. The motivation of the study presented here is to analyse the curriculum of one specific high school type: the *Liceo Scientifico*. The reason: this type of school physics is studied for the entire five-year period. And, this school dedicates more time to studying physics than any other type of schools in Italy. The scientific lyceum high school offers three possible curricula of study; Traditional (*Tradizionale*), Applied Sciences-Option (*Opzione Scienze Applicate*) and Sports-Section *(Sezione ad Indirizzo Sportivo*). For all three, the physics discipline's section of curricula adopted are the same with some minor adaptations. Each year, thousands of students enrol in these type of schools. In 2019/2020 the total number of application forms for all the secondary schools was 542,654 (MIUR, 2019, p. 3). The these, 94.7% of th students chose high school, the rest chose education and professional training (5.3%). Between the three types of high school, most students chose the *Liceo* (54.6%), and more specifically, 25% of students choose the *Liceo Scientifico*, of which 15.2% the Traditional one, 8.2% the Applied Sciences-Option and 1.6% the Sports-Section (MIUR, 2019, p. 10). The *Liceo Scientifico* curricula impact so many teachers and students' learning experience. The Italian curriculum is not unique and like many curricula globally, it too does not have a specific component for NOS. The curriculum document will be described in the next section, to demonstrate the importance of analysing this specific curriculum. Our methods will be useful for other countries as an example of how to analyse curricula with no specific NOS component.

On the 15th of March 2010, the legislative decree that describes the organisation and didactics of the *Liceo* high school in Italy has been issued. In annex F of the decree, a table explains the study plan the teachers and students must follow during the five years of the *Liceo Scientifico* school (MIUR, 2010b). The table also indicates the hours of lessons per year for each discipline; the document states that physics requires a minimum of 66 hours per year during the first and second year (grades 9–10) , then 99 hours per year during the last three years (grades 11–12–13) of schooling (MIUR, 2010b). The ethos of the study plan outlines how its aim is to favour the acquisition of knowledge and methods of mathematics, physics, and natural sciences. The same year, another decree, the *Italian National indications* was issued (MIUR, 2010a). It consists of recommendations, aimed to orient schools and teachers and provide a common framework for all the schools of the country. They have been explicitly outlined to be non-normative and non-prescriptive. At the back, there is the idea that teachers have to be autonomous whereby they are taking into account variable factors, such as the students, the environment, and of course their own vision for teaching approaches. In the annex F of this decree, there are the indications specific for Liceo Scientifico school. In the analysis, we focused the attention on the physics discipline's section, which we refer to now going forward as 'the document'. It is important at this stage to draw the distinction between the parts of the curriculum document. It is organised into two main sections; the first one titled 'General lines and comptences', includes the scope and competences that are expected to be developed throughout the five-year path. The second part is entitled 'Specific learning objectives', articulates the physics content knowledge and themes (e.g. kinematics, optics) along with a description of learning objectives. In the article we will call them, respectively, 'Section G' and 'Section S'. Another important note is that the Section S is articulated in three sub-sections, referring to the different grades: first biennium (grades 9–10), second biennium (grades 11–12), fifth year (grade 13). We will call them respectively 'S9–10', 'S11–12' and 'S13'. These two decrees (MIUR, 2010a, 2010b) updated the previous curriculum (MIUR, 2005), that was in effect from November 2005 until 2010.

Methodology

The empirical study was guided by the following primary research question: *How can FRA and ENA be used for analysing NOS content in science curricula?* Using the FRA as an analytical framework, the curriculum was investigated to determine what area of the curriculum contained aspects of the NOS from the perspective of the FRA framework. Content analysis describes a range of analytic approaches, from impressionistic, intuitive, interpretive analyses to systematic, strict textual analysis (Hsieh & Shannon, 2005; Rosengren, 1981). We applied a strict and systematic set of procedures for the rigorous analysis, examination and verification of the contents of written data (Cohen et al., 2007). The precise type of content analysis methods chosen by a researcher is often determined by the theoretical and substantive interests of the researcher and the problem being studied (Hsieh & Shannon, 2005; Weber, 1990). In the case of our study, we implemented a strict text analysis. The coding was conducted independently by two researchers; any disagreement or potential misrepresentation of the data was resolved through discussion and one such example is as follows. We were careful in our analysis not to reflect any of our own biases as educators and make inferences about the curriculum content if it was not explicitly written in the document. We tried not to infer what we ourselves as educators would include when teaching the learning objective or topic. For example, the document referred to nuclear energy. We agreed as educators that if teaching this topic we would include features that would align with the social values of the science category and discuss features around how nuclear power has implications for the environment, it's a social utility and how it addresses human needs. However, the learning objective did not mention or include these wider societal issues and so this rigid approach became part of the strategies used in the analysis. As we show above, the nature of qualitative data often makes it difficult to separate personal experience during the interpretation of the data in the analysis phase. There are ways to maintain objectivity and avoid bias and increase reliability with qualitative data analysis and we outline the concrete steps used during the analysis in the following section entitled 'Analysis Criteria and Reliability'.

The analytical methodology used a theory-driven approach to determine the analysis criteria and it is shown with some illustrated examples of the classification process. The intention was to analyse the text and find the presence of the categories in the curriculum. Table 2 illustrates how the text was put into sections. The first column indicates the section that the text was obtained from within the document; sub-section 3.6. The text is in the next column. A column was used for each of the following FRA categories in the cognitive-epistemic system. The last column represents all the categories from the social and institutional system. The findings from the analysis of the text showed that in most cases the text was classified into only one category from the FRA framework. However, there were cases where the text related to different parts of the framework. Table 2 shows such an example, the text contained a number of instances related to multiple parts of the FRA framework, each part was underlined and a letter denoting its presence was marked and recorded in the column indicative of the category. For example, 'experimental dimension' was underlined, as experimental aspects are an investigative method in physics, and relates to ideas presented in the methods and methodological rules category. Then, 'activities' is discussed in relation to the scientific practices category, as science activities such as observation or experimentation are practices. The text

Table 2. Example theory-driven analysis of the Italian curriculum document with the FRA framework.

		Cognitive-epistemic system				Social and institutional system
	Specific learning objectives Fifth year	Aims and values	Scientific practices	Methods and methodological rules	Scientific knowledge	
S13.6	The <u>experimental dimension</u> (B) can be further deepened <u>with activities</u> (A) to be carried out not only in the school's didactic laboratory, but also <u>in universities and research institute laboratories</u> (C)		•A			•B Social organisation and interactions

discussing ‘universities and research institutes laboratories’, was classified within the Social organisation and interactions, because this particular category in the FRA framework describes science as socially organised into research centres and universities.

Analysis criteria and reliability

Further to the issues of content analysis, procedures for analysis were outlined in order to classify the curriculum document content. The authors needed to develop analysis criteria to ensure that the results were valid and reliable. The authors initially analysed the document individually, in order to obtain a baseline for the categorisation. The authors went through every instance of disagreement and reconciled the judgments following discussions which set key guidelines or criteria for classification:

(1) As the framework is fluid and interwoven (Erduran & Dagher, 2014a), some items were present in more than one category, and so it was decided through discussion that the same piece of text could be classified in multiple categories. For example, the curriculum discusses the ‘predictive nature of physical laws’ in subsection S11–12.1. Prediction is discussed in both the aims and values category and the practices category. Therefore, ‘prediction’ was counted in both categories.
(2) When a statement was deemed to relate to one category only, then it was only recorded once regardless if the text had multiple references to that category. For example, in subsection S11–12.5, the statement made multiple references to different theories, laws and principles in physics (kinetic theory, gas laws and principles of thermodynamics). These concepts relate to the knowledge category, but all these instances were only counted once in the tally.
(3) Some instances were reconciled through discussion when it was noticed that inferences were made about the text from how the authors would potentially teach the content. Therefore, to ensure that our study implemented strict text analyses (Hsieh & Shannon, 2005), we removed any instances where there were not explicit references to the aspects in the text. For example, section G.6 refers to ‘the society in which the student lives’. We agreed as educators, we would include features of social organisations and interactions and financial systems, as well as social values of science. However, as this was inferred from reading the text and it did not explicitly mention social organisations, interactions and financial systems, and so were removed.
(4) Finally, there were some instances that were misclassified in the individual process. There was a triangulation process implemented with the authors themselves, consultation with the publication (Erduran & Dagher, 2014a) as well as published studies that used similar approaches (Cheung, 2020; Yeh et al., 2019) and the concepts outlined in Table 1. Unless there was a shared presence, in these documents and the authors’ observations, then the instances were not recorded.

After each round of analysis and refinement of the analysis criteria, percentage agreement was calculated by using inspiration from Miles and Huberman (1994). One (1) was recorded when there was a match, and zero (0) was recorded when there was no match or a disagreement. All these matching instances were counted and divided by the total number recorded. According to their methods, Miles and Huberman (1994) suggest anything over 80% agreement is a good indicator of reasonable reliability.

Epistemic network analysis

Epistemic Network Analysis (ENA) is described as an innovative approach to displaying the connections between data in a graphic image. There is limited research in science education using ENA along with FRA for document analysis (e.g., Cheung, 2020). ENA was initially developed to model cognitive networks based on the assumption that the structure of connections among cognitive elements is more important than the mere presence of those elements alone (Shaffer et al., 2016). The ENA can be applied to all contexts to manage complex networks of relationships among small, fixed elements. For example, this method of analysis and representation has been used to visualise how people connected NOS ideas (Peters-Burton et al., 2019). The aim of the analysis is to discover not only which NOS categories are present in the physics curriculum, but also which categories are interconnected and how that is what holistic structure emerges. The ENA presented here shows the relationships found between NOS categories in the Physics curriculum. We produced the ENA analysis, using the Online ENA Tool (www.app.epistemicnetwork.org), free available to allow everyone to develop his/her own epistemic network analysis. A helpful tutorial (Shaffer et al., 2016) has been created to explain the theory behind ENA and to detail the process by which the ENA tool creates a network model. The results of our analysis that are also reported in Table 2 were used to perform the ENA analysis.

The network analysis works in the following way. Every time more than one category in a statement has been found, a link between these categories is made by the software. If only one category is found in a statement, no links are created (Peters-Burton et al., 2019; Shaffer et al., 2016). To analyse the agreement between the authors' results, two ENA analysises on the separate authors' results were produced and then compared; to analyse the final connections found between the FRA categories, the sum of their analysis was used rather than individual analysis. For example, looking at the case in Table 2, the analysis led the authors to recognise three categories in the statement S13.6. So, in this case, the ENA analysis will show the connections between those categories. ENA analysis allows immediate understanding of which categories are more connected and which are not. That is because the most frequent connections are represented as thicker lines. The categories, that are the basic elements of the network, are represented as black dots, flanked by the corresponding name. Once the strongest connections have been found, they can be tested against the document statements to check their significance.

Results and findings

Once the initial individual analysis was completed, the authors compared results. One author classed 58 instances and the other classed 35 instances. This first round of analysis found that there was a combined count of 64 instances of NOS in the curriculum and these evaluations resulted in a percentage agreement of only 46.9%. These included both instances of agreement (30) and disagreement (34). A reconciliation procedure took place that allowed us to develop the analysis criteria outline above, which resulted in 52 instances (see Table 3). In terms of individual analysis, one author reconciled their count from 58 instances to 49 instances. The other author reconciled their count from 35 instances to 47 instances. Following the reconciliation process, there were 44 overlapping instances of agreement and 8 instances of disagreement, leaving the overall percentage agreement to be 84.6%. Table 3 shows where agreement was met. There were several times when 100% agreement was reached for certain categories such as aims and values, professional activities, scientific ethos, social certification, social organisations and interactions, and political power structures categories. Each author found there to be three instances of the aims and values category, and the authors agreed on all three. Similarly, the authors agreed that there were no instances of the social-institutional activities category in the document and so there was complete agreement there as well. Of the 11 categories in the FRA framework, the authors agreed on the presence or absence of NOS instances across 6 of the different categories. Although there wasn't complete agreement across the other five categories, there were still high levels of agreement. In total, our analysis shows that of the 52 instances of NOS classified, and within those, only 6 (11.5%) of those instances related to aspects within the social institutional system aspect, and no social-institutional category was found in the curriculum document relating to the first two-year period. (See Figure 4(a) in the ENA section for evidence of this claim.) These results such as this would indicate the lack of representation of these features in the curriculum.

The results show that the curriculum has several instances related to the knowledge category (22), followed by practices (12), then methods and methodological rules (9), and then aims and values (3). The analysis of the document found that there were limited instances from the social-institutional aspect (6), which includes features of social certification and dissemination (1), social values of science (2), social organisations and interactions (2) and financial systems (1). The analysis showed there were no instances of professional activities, scientific ethos, and political power structures. Other studies, too, have reported this particular imbalance in the science curricula of Ireland (Erduran & Dagher, 2014b), in Turkey (Kaya et al., 2019) and Taiwan (Yeh et al., 2019). The table shows the limited scope of the curriculum in terms of NOS representation and opportunities. As expected, the knowledge category had many instances, followed by the methods and practices categories. Unfortunately, the curriculum presented a narrow scope of science as a social institutional system aspect, with only six recorded instances, in total.

Table 3. Results of the percentage agreement between authors for the FRA categories; aims and values (A&V), scientific practices (P), methods and methodological rule (M&MR), scientific knowledge (K) in the cognitive-epistemic system, and professional activities (PA), scientific ethos (ScE), social certification and dissemination (SCD), social values of science (SVSc), social organisations and interactions (SOI), political power structures (PPS) financial systems (FS) in the social-institutional aspect.

	Cognitive-epistemic				Social institutional							Tot
FRA categories	A&V	P	M&MR	K	Act	Eth	Cert	Value	Org	Pol	Fin	
Matching count	3	10	8	19	0	0	1	1	2	0	0	44
Different count	0	2	1	3	0	0	0	1	0	0	1	8
Total count	3	12	9	22	0	0	1	2	2	0	1	52
Percentage agreement 84.6%												

Findings from epistemic network analysis

The finding of our ENA concern the total connections found by the authors in the whole document and the different parts of the document. The total connections found by the two authors are depicted by the image in Figure 2. The central black dot represents the categories (Political Power Structures, Scientific Ethos, Professional Activities) which are not linked to the others. The most frequent connections are seen between scientific practices and scientific knowledge, scientific practices and method and methodological rules, and scientific knowledge and method and methodological rules. Less tangible connections exist between aim and values and scientific knowledge. The less frequent connections are seen between categories belonging to two different systems (cognitive-epistemic system and social-institutional system) or between the individual categories of the social-institutional system.

Figure 3a and Figure 3b present the connections found in the curriculum document. Each image provides the results of the analysis to illustrate the connections found in the document's section G (general) (Figure 3a); the connections found in document part S

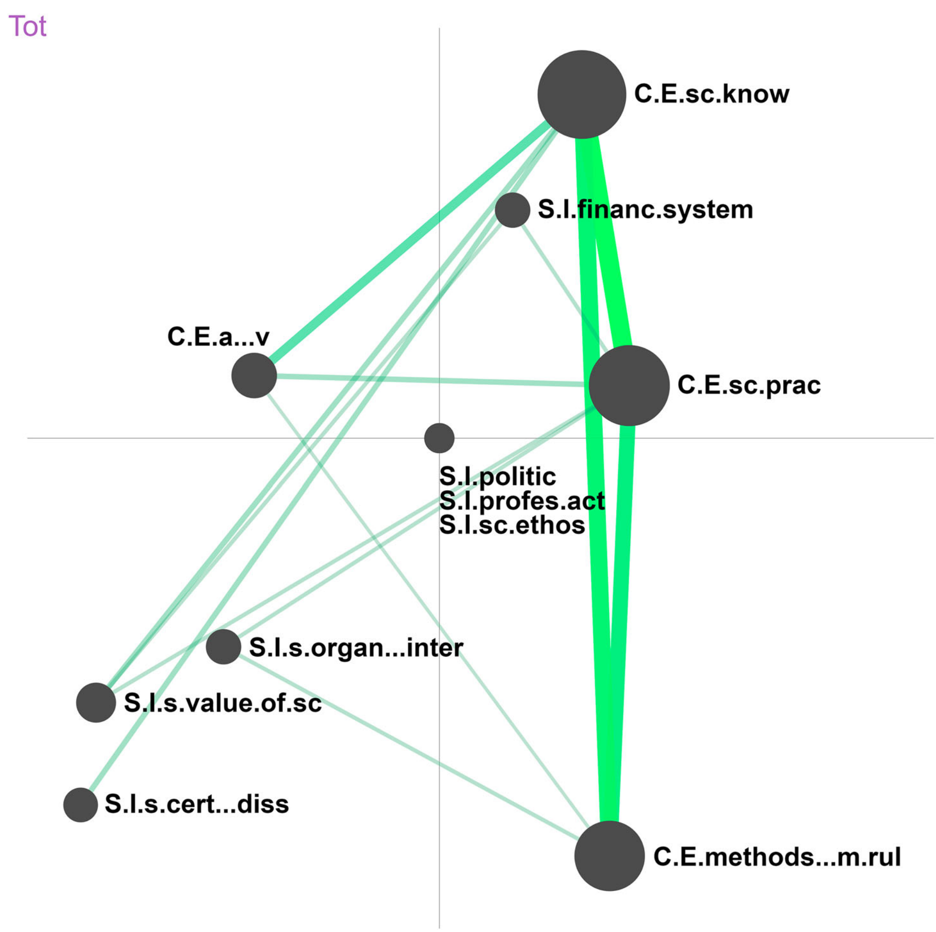

Figure 2. Overview of all connections across FRA categories.

(specific) (Figure 3b). Looking at the curriculum in more detail, analysis was carried out of the stages of study in the five years of high school. Figure 4(a–c) presents the connections found in the different document sections Section S_{9-10}, which relate to year 1–2 of high school, Section S_{11-12}, which relate to years 3–4 of high school, and Section S_{13} which relate to the fifth and final year of study in high school.

In both these analyses, there is a notable lack of connections with the NOS categories related to the social-institutional aspects. Similar to other studies that used this type of analysis to look at curriculums and assessments (see the work of Cheung, 2020), we also found that the NOS categories in relation to the social-institutional system are often not emphasised in the curriculum content. The connections between the 'social organizations and interactions', 'political power structures', and 'financial systems' are key features of the FRA framework and they are retained to be vital to students' understanding of how scientific enterprises work within social and cultural milieu (Erduran & Dagher, 2014a). Nevertheless, the results from this study, as well as studies by Cheung (2020), Yeh et al. (2019), Erduran and Dagher (2014b) and Park, Wu, et al. (2020), highlight an insufficient presence, articulation and interconnections among these categories.

The second aspect emerges from the comparison of the figures related to the general section G of the curriculum document (see Figure 3a) and to the specific section S of the curriculum document (see Figure 3b). The graph related to the general section G is characterised by a rich range of connections. The connections between the cognitive-epistemic categories of NOS (A&V, K, Pr, Methods) appear strong. Among these, the strongest appears between 'practices' and 'method and methodological rules'. A qualitative analysis of these connections highlights that they are explicit and significant because they emerge from sentences like the following one: 'experiencing and explaining the meaning of the various aspects of the experimental method i.e. the reasoned inquiry of natural phenomena, the choice of significant variables, the collection and critical analysis of data' (G.5). In the general section G, another important type of connection exists between 'aims and values' and 'knowledge'. This connection emerges explicitly in

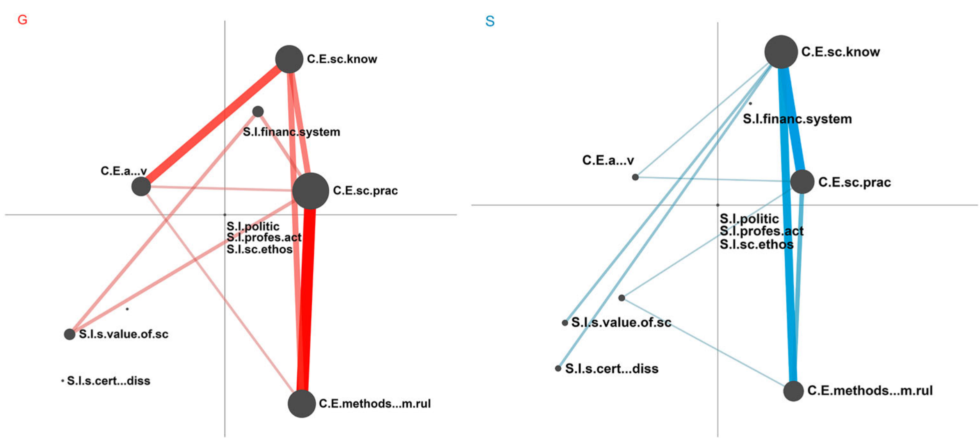

Figure 3. Representations about the connections found in the curriculum document. Each image provides the results of the analysis to illustrate the connections found in the document section G (general) (Figure 3a); the connections found in document part S (specific) (Figure 3b).

statements like 'the understanding of the fundamental concepts of physics, the laws and theories, helps the students in becoming aware of the cognitive value of the discipline' (G.1). In statements like 'model construction and validation' (G.5), the connection is more implicit since its recognition implies reason on the fact that the model to be valid must satisfy certain values that make it scientific. The figure related to the specific section S (Figure 3b) appears very different from the previous one and much focused on the knowledge node. Here, the strongest connections are between 'knowledge' and 'practices'. An example of the link is in the following statement: 'through the study of geometric optics, the student will be able to interpret the phenomena of light reflection and refraction and the functioning of the main optical instruments' (S). In this sentence, the link emerges by taking 'geometric optics' as knowledge, and 'interpreting

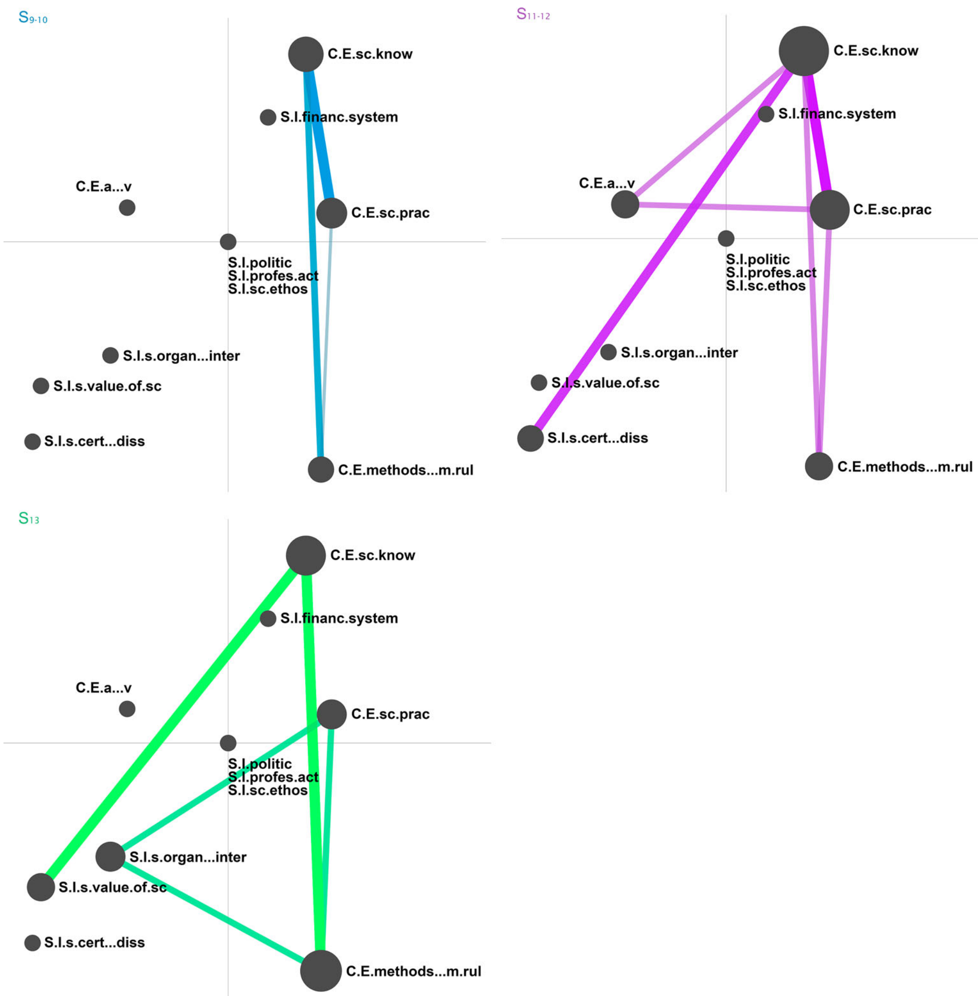

Figure 4. Representations of the connections found in the specific section of the curriculum document. Each image provides the results of the analysis to illustrate the connections found in the specific section regarding the first two years S_{9-10} (ISCED levels 9–10) (Figure 4a); in the second two years of physics course S_{11-12} (levels 11–12) (Figure 4b); in the last year S_{13} (level 13) (Figure 4c).

phenomena' as practices. The distinction between the general and the specific sections resonates with the different roles that the two sections are supposed to play: whilst the former aims to frame teaching within cultural, epistemic and pedagogical scopes, the latter section aims to point out the specific science content that has to be dealt with in class to pursue specific learning objectives.

However, the difference between the two sections deserved further investigation. Thus, we decided to unpack the specific section of the curriculum and search for the NOS structure within the three subsections of the specific part of the document: the sub-section related to the first biennium S_{9-10} (the first two years or grades 9–10) (Figure 4a), the sub-section related the second biennium S_{11-12} (grades 11–12) (Figure 4b), the sub-section related to the fifth year S_{13} (grade 13) (Figure 4c). By splitting them up, it emphasises problematic elements within the document. The sub-section related to the first biennium of high school (Figure 4a) presents only three elements connected, all belonging to the cognitive and epistemic system: practices, knowledge and methods. Here the links only exist between the cognitive and epistemic categories. This image shows clearly that the focus on knowledge makes the structure of connections between NOS elements collapse and disappear. The distance between the NOS structure of Section G (Figure 3a) and the NOS structure of the subsection of the first biennium (Figure 4a) can induce to think that a 'developmental approach' is implicitly implemented in the curriculum. According to this approach, we would expect to see, in the following grades, a progressive enrichment of the NOS structures. Unfortunately, the image related to the second biennium and the fifth year (Figure 4b, c) do not seem to support this hypothesis. Their NOS structure remains less articulated than the NOS structure of the general part. Furthermore, a qualitative analysis of the connections shows that a larger ratio of connections in the specific part refers to neither explicit nor particularly strong links. All these elements led us to see several issues in the curriculum that are worth to be stressed both for teachers and for policymakers.

Conclusion and discussion

The multiple studies that are emerging which use FRA as an analytical tool (e.g. Cheung, 2020; Erduran et al., 2021; Kaya & Erduran, 2016; McDonald, 2017; Yeh et al., 2019) indicate that it is not only a relevant framework for analysis due to both its domain specific and domain general characteristics (e.g. physics versus biology as domains), but it also provides a holistic view of how science is presented in the curriculum. Rather than a generic characterisation of 'science' in relation to NOS, the FRA framework facilitates capturing domain-specific features of different aspects (Erduran & Dagher, 2014a). A holistic understanding of NOS is crucial not only for its value for enabling reflection on how science operates in the real world, but also because of its interconnectedness that enables students to understand why and how science works (Yeh et al., 2019). The particular context of the Italian curriculum points to some of the limitations in terms of how different aspects of NOS are covered in the curriculum. The issue of inclusion of particular NOS content as well as establishment of the interconnections between ideas is relevant not only to the particular Italian context here but more broadly to the design of curriculum standards more widely across the world.

The general and the specific section of the Italian curriculum (Figure 3a,b) have different NOS structures and these differences cannot be explained simply in terms of the different roles of the two sections. It instead sheds light on a feature of the curriculum that the teachers often perceive: a sort of detachment between the aims/values claimed in the general section and the contents' description reported in the specific part of the curriculum document. Even though connections between NOS elements are recognisable in the general part of the curriculum document, they do not always appear significantly related to knowledge when the contents are described. This difference between the two sections leaves room for teachers to decide to deal with NOS according to their style, tastes, and epistemological stances. However, the collapse of the NOS structure and the lack of any development approach seem to support the hypothesis that the curriculum does not simply leave room for teachers, but that it has inner weaknesses and possible inconsistencies. However, these observations raise empirical questions regarding curriculum design and implementation. The study has implications for further research with regards to how teachers themselves might interpret the curriculum standards, as well as applications of the methodology to other curriculum, globally. It would be beneficial to conduct a comparative study between curriculum standards and teachers' interpretations of those standards to see the extent to which teachers might be mediating interconnections between curriculum standards in teaching practice. In other words, although our study is significant in terms of illustrating disconnection between ideas, it could be that teachers themselves link up ideas in their teaching practice (Shulman, 1986). Future studies could interview teachers to investigate how they interpret the statements for teaching purposes and do a comparison to illustrate the diversity or uniformity of teaching approaches.

The methodological approaches used in the paper enable us as researchers to trace the lack of any evidence of a developmental path for helping teachers teach NOS in physics lessons. The data from the analysis of the curriculum backs up claims of how the FRA framework is not compartmentalised but flows into one another. The ENA analysis shows if and how these connections are present in curricular documents. It is the hope that these network connections will help in curriculum development and teacher education programmes, where they might want to develop NOS instruction and strategies using curriculum documents. Furthermore, the epistemic networks illustrated in the paper provide concrete illustrations of where curriculum revision can best be placed to promote underrepresented aspects of NOS. Due to its broad nature, the FRA has affordance for pointing to all the components of the cognitive-epistemic and social-institutional systems interact with one another, enhancing or influencing scientific activity. The ENA analysis extends the potential of FRA to illustrate the precise connections that need to be made for the curriculum to be coherent (Cheung, 2020).

Although the study was conducted with Italian curricula, it has implications for curriculum analysis in other parts of the world and for broader goals. In particular, it pointed out a strategy to recognise whether curricula give back a faithful and articulated idea of what makes a body of knowledge a discipline. The collapse of the NOS structure that our analysis pointed out in the Italian curriculum, when one moves from the General to the Specific part, shows that knowledge gets lost in its inner disciplinary structure. FRA, together with ENA, shows that both the epistemic dimensions and their connections disappear, by leaving only a list of notions. In this society of uncertainty where knowledge is fragmented in data and pieces of information, it would be very important that also the official documents play an important role promoting teaching as a way to equip the young with epistemic skills, that are needed to make sense of the complexity of our world. Being able to recognise the multiple dimensions of knowledge with sensible and robust connections and arguments are indeed more and more fundamental competences in our society. The results we have obtained here are an example of where and how official documents can fail and should act.

Foremost, the methodological approaches of using FRA as an analytical framework as well as the ENA approach are noteworthy. The FRA categories can potentially orient curriculum research in other parts of the world as they are fairly generic and comprehensive and can be adapted to other national contexts. This aspect has already been confirmed through other studies that have adapted both approaches in different ways to analysis of curriculum and assessment documents, for example in Hong Kong (Cheung, 2020). Furthermore, science educators from different parts of the world can potentially benefit from examining details of other countries' curricula to help them orient their own curricula and to learn from different content and approaches. Although numerous curriculum standards documents have included NOS for as early as the 1980s (e.g. AAAS, 1989) there is still much space within curricula to clarify and enrich the content about NOS. The research reported in the paper thus contributes not only to the study of NOS from an FRA perspective (e.g. Akbayrak & Kaya, 2020; Akgun & Kaya, 2020; Erduran & Dagher, 2014b; Erduran & Kaya, 2018; Mohan & Kelly, 2020; Park, Seungran Yang, et al., 2020; Petersen et al., 2020) in the context of curriculum analysis but also it has practical implications for curriculum policy reform.

Acknowledgement

The paper is the result of a collaborative study that started with the Erasmus + traineeship of Martina Caramaschi at the University of Oxford under the supervision of Sibel Erduran and Alison Cullinane, with Olivia Levrini as the main supervisor at the University of Bologna.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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