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APPLICATIONS OF RFN (Reconceptualized Family resemblance approach to Nature of science) TO HIGH SCHOOL PHYSICS TEACHING

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To Joy Francisca and to all those people,
who enriched me over these years with their lives.

A Joy Francisca e a tutte quelle persone,
che mi hanno arricchita durante questi anni con la loro vita.

"Once, my teacher said a beautiful phrase: 'Culture is what remains when we no longer remember anything'. In this sense, I think that physics gives us so much, even though one day we won't remember anything anymore." - p. 56

"Una volta il mio insegnante mi disse una frase bellissima: 'La cultura è ciò che rimane quando non ci ricordiamo più niente'. In questo senso, credo che la fisica ci dia molto, nonostante un giorno non ci ricorderemo più niente." – p. 56

Abstract

This thesis project fits into the research's area of science education called Nature of Science (NOS). The aims of the thesis are: to understand what "image of physics" emerges in high school teaching; to provide suggestions to recognise implicit or explicit limits and potentialities of the official curriculum to guide, in class, students to get acquainted with the authenticity of science and its societal relevance.

The thesis contains two studies. Both of them have been carried out by using a well-known framework in science education: Reconceptualized Family research approach to Nature of science (RFN) by Erduran and Dagher (2014). The framework has been used in the first analysis to investigate the presence of NOS elements in physics guidelines adopted by the "Liceo Scientifico" high school in Italy. The study highlighted a significant presence of epistemic and cognitive aspects of science in the guidelines, in contrast to a scarce presence of social and institutional aspects of science. Through an Epistemic Network Analysis (ENA) on the connections between the NOS categories in the curriculum, a structural difference emerged between the general part of the guidelines, where the goals and values are mainly stressed, and the specific part, where the contents are described. In the latter, the main node of connections is "knowledge", making the other NOS categories little valued.

The second analysis uses RFN to investigate how a sample of five physics teachers implemented, in their teaching, NOS elements related to epistemic and cognitive practices. The results highlighted not only the room that teachers can find to teach NOS, independently of the official guidelines, but also the great relevance that these elements can have to boost understanding in the discipline, to authentically engage students with physics, and to develop cultural and emotional skills crucial for becoming a responsible and aware citizens.

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Introduction

From personal inputs to the thesis

Thinking at my personal experience as physics student during high school, I remember I have studied a lot of physics laws and theories. Sometimes I had the opportunity to overcome physics laboratory door, looking at experiments and touching with my hands some physics equipment. I remember that physics for me was synonym of formulas, tests, exercises ad laws. I admit that I initially chose to study physics at university because during high school I was proficient in physics, “that physics”. Despite my high school was markedly scientific-oriented, in my class I was one of the very few who chose to continue to study physics at university. The classmates who explicitly enjoyed physics were approximately a quarter of the students. This made me think that maybe “that physics” did not passionate enough. Always in that period of my educational path, I had the impression that physics and other scientific disciplines, I have studied during high school, like chemistry or biology, had nothing to do each other and they appeared as separate disciplines.

Today, after studying physics at university for several years, I experienced that physics is much more than “that physics”. For example, we could think about its epistemology, its links to society and cultures (of past, future and present), its values, its methods, its links to reality around us. Instead, during high school, I got the impression as if I had only seen just one face of physics. Apart from this, I realized both that physics can be of interest to a wide range of students in many ways (for example, how it is involved in solving everyday life socio-scientific issues; how it builds knowledge; the stories of people who made it and how physicists works); and also, that physics acts into a larger group: the scientific disciplines. Even if they are unique, all have much in common and, often, one enriches the others. The fast growth of interest to STEM projects makes me think that they will work together more and more often.

These discoveries, in contrast to my (absolutely personal) experience in high school, led some questions to raise. Questions like (a) “how can we give an authentic idea of what is physics and what does doing physics mean for high school students?”; (b) “how can we generate curiosity and interest for physics in a large group of students?”; (c) “how can we help students appreciate the bridges between scientific disciplines, recognise differences and commonalities between them?”.

The thesis I try to support in this work is that a teaching approach to physics in high school that shows both the complexity and the uniqueness of this discipline, can contribute to:

- make physics more understandable for students.
- involve most of the students (because a plurality of aspects of the discipline are shown).
- make them aware of the cultural importance of physics as citizens.

Thesis aims and structure

The thesis project aims to study the “image of physics” that emerges in high school teaching. Attention is paid to discover which aspects, characterizing the epistemology of the discipline, are treated and how, in official documents and in classroom activities. In particular, the thesis project aims to discover what physics curriculums, adopted in high schools, have to offer, in relations to cognitive, epistemic, social and institutional aspects of science. Then, the thesis project aims to give potentially suggestions to recognise implicit or explicit limits and potentialities that the official curriculum has to orient teachers in guiding students to get acquainted with the authenticity of science and its societal relevance.

These objectives are practically implemented by analysing the presence of elements of the Nature of Science within the high school physics guidelines. Moreover, by listening and analysing the point of view of high school teachers, about some aspects of Nature of Science in physics and of its teaching to students.

The thesis is articulated on three chapters. The first two chapters concern studies and the project carried out during the Erasmus period at the University of Oxford, under the supervisions of Prof. Sibel Erduran and Dr. Alison Cullinane.

In the first chapter, I describe the theoretical basis of this thesis project: starting from the meaning of Nature of Science and its importance in science education, I illustrate some important perspectives regarding Nature of Science, and then the Family Resemblance Approach to Nature of Science, which is the theoretical framework I have mainly adopted. At the end of the chapter, I focus on a reconceptualised version of Family Resemblance Approach (RFN), that is specifically oriented to Science Education.

In the second chapter, I describe how I have used the RFN to investigate the presence of Nature of Science in physics guidelines, adopted by Italian high schools: I describe the analysis aims and methodology adopted and the results.

In the third chapter, I report the analysis of five interviews carried out to physics teachers on how and why they implemented, in their teaching, elements of Nature of Science. I focus on scientific practices, analysing teachers’ point of view. In the chapter, I describe the aims of analysis; how the data have been collected; the analysis methodology and the results achieved.

Chapter 1. Family Resemblance Approach to the Nature of Science for Science Education

1.1. Nature of Science for Science Education

This thesis project fits into that research's area of science education called Nature of Science (NOS). This research field deals with understanding two important questions: what science is (including issues like: "how can we approach this question?" and "is this question well posed?"), and which are its fundamental aspects that should be taught in school. These two elements are far from being simple to define. The first question has involved philosophers of science, scientists, and sociologists, working over the centuries to find ways to delineate what science is and what its nature is, and leading to rich and very often conflicting results. This variety of results is due not only to the different fundamental points of view about Science, but also to the multiple methodological approaches used to delineate the boundaries of Science, that are usually built by referring to a specific area of science. The second question necessarily collides with the fact that science covers various a great multiplicity of fields, that imply different areas of competence, and different features of NOS, making challenging to decide which aspect should be taught and which not (Galili, 2019).

For science education, student's understanding of NOS has been considered an important goal since the beginning of the XX century. The first interest is found in the reports of the Central Association of Science and Mathematics Teachers (1907) in which a strong argument was presented to highlight the relevance of teaching the scientific method and the processes of science. After that, numerous works were developed. For example, in the 1960s Klopfer, who studied the nature of scientific knowledge, identified the understanding of how scientific ideas are developed as one of the three important elements of scientific literacy (Klopfer, 1969). A more recent study is developed by Allchin, in 2013, that proposes a perspective on nature of science that was considered by the author *as a manifesto for a more holistic view of how science should be taught* (Allchin, 2013).

Reasons why learning NOS is considered a central goal in science education are many. By National Science Teaching Association, it contributes to develop scientific literacy (1982). According to Driver, Leach, Millar and Scott (1996) five potential benefits came from students' understanding of NOS: it helps students to (a) make sense of science and manage the technological objects and processes in everyday life, (b) make informed decisions on socio-scientific issues, (c) appreciate the value of science as part of contemporary culture, (d) understand of the norms of the scientific community that embody moral commitments that are of general value to society, (e) learn science content with more depth (Driver, R. *et al.*, 1996).

Briefly, what we have seen is that NOS contains those elements that stimulate the reflection on what science is; precisely, it encourages us to consider the historical and current debates on what its nature is. Having an adequate understanding of NOS is considered important to make sense of the study of the scientific disciplines themselves and to understand them in a richer way. But what is the definition of NOS?

1.2. NOS demarcation: different perspectives

In spite of the wide consensus on the importance of the nature of science for teaching/learning, there is little accordance, within the community of philosophers and science educators, about how can we approach the question of defining what NOS is (Irzik & Nola, 2011). From the decade of 1960s, extensive work was carried out in science education regarding the definition of NOS. This discussion was, of course, strongly informed by the debate that occurred in philosophy since the end of XIX century. Among the many protagonists of that debate, I remind only some fundamental contributions, like “The logical structure of the world” by Popper (1935), “The structure of scientific revolutions” by Kuhn (1962), “Falsification and the methodology of scientific research programmes” by Lakatos (1970) and “Against method. Outline of an anarchistic theory of knowledge” by Feyerabend (1975).

In this thesis, I present some perspectives, which will help to clarify, later on, the theoretical line that I have chosen to adopt in this thesis.

The first work I intend to show is a good example of how arduous it is to find a common definition of NOS. Osborne, Collins, Radcliffe, Millar and Deschl (2003) have studied an expert community (composed by science educators; scientists; historians, philosophers, and sociologists of science; experts engaged in work to improve the public understanding of science; and expert science teachers) in order to understand what ideas about science should be taught in school. The findings, as Erduran end Dagher (2014) observe, have shown that there are few themes on which a shared position from experts is found: five themes fall under the umbrella of the Methods of Science (experimental methods and critical testing, creativity, science and questioning, diversity of scientific method, and analysis and interpretation of data); two themes under the Nature of Scientific Knowledge (historical development of scientific knowledge, and science and certainty); one under the heading of the Institutions and Social Practices of Science. The authors in the same work declare that do not exist a method or a group of people able to give a universal and definitive answer to what should be the essential elements of a contemporary science curriculum (Osborne *et al.*, 2003).

One of the most adopted frameworks in science education is called the “consensus view”. It has led to a major body of empirical studies in science education. This framework was outlined by

Lederman, Abd-El-Khalick, Bell and Schwartz (2002). Aware that controversies still exist regarding the definition or meaning of NOS, they argue that disagreements are irrelevant to K-12 instruction. Moreover, at this level of education, "*some important aspects of NOS are not controversial*" (Lederman *et al.*, 2002, p. 499). A set of aspects concerning NOS, which are said by the Authors to be shared, were outlined and it constituted the basis of the "consensus view" framework[1]. According to this framework, NOS is comprised of the seven elements shown in table 1.

Table 1.1. Elements of the nature of science from the "consensus view" (Erduran and Dagher, 2014) – Adapted from Jho, (2019, p. 601)

Element	Description
Tentativeness	Scientific knowledge, although reliable and durable, is never absolute or certain. This knowledge, including facts, theories, and laws, is subject to change.
Observation and inference	Observations are descriptive statements about natural phenomena that are directly accessible to the senses (or extensions of the sense). By contrast, inferences are statements about phenomena that are not directly accessible to the senses.
Theory-ladenness	Scientific knowledge is theory-laden. Scientists' theoretical and disciplinary commitments, beliefs, prior knowledge, training, experiences, and expectations actually influence their work.
Creativity and imagination	Science is empirical. Nonetheless, generating scientific knowledge also involves human imagination and creativity.
Socio-cultural embeddedness	Science as a human enterprise is practiced in the context of a larger culture and its practitioners are the product of that culture.
Scientific theories and laws	Scientific theories are well-established, highly substantiated, internally consistent systems of explanations. Laws are descriptive statements of relationships among observable phenomena. Theories and laws are different kinds of knowledge and does not become the other.
Myth of scientific method	The myth of scientific method is regularly manifested in the belief that there is a recipelike stepwise procedure that all scientists follow when they do science. This notion was explicitly debunked.

Interesting constructive remarks regarding "consensus view" and a new approach to NOS are provided by Irzik and Nola (2011; 2014). Below, I dedicate a paragraph to them, because their perspective on NOS represents the basis from which the theoretical vision, that I have adopted in this work, starts.

1.3. Family Resemblance Approach to NOS

In the first part of their work, Irzik and Nola (2011) bring to light some observations regarding the completeness of the "consensus view" vision of NOS. They believe that several characteristics of science, included in the list, are largely agreed upon, as, for example, that scientific knowledge is empirical (relies on observations and experiments); reliable but tentative (i.e. subject to change and

[1] It is correct to remark that the facts that "*some important aspects of NOS are not controversial*", or that this framework represents a vision of consensus in science, have been plurally criticised (Galili, 2019; Matthews, 2012; Osborne *et.al.*, 2003).

thus never absolute or certain); partly the product of human imagination and creativity; theory-laden and subjective (that is, influenced by scientists' background beliefs, experiences and biases); socially and culturally embedded (i.e. influenced by social and cultural context); and, that there is no single scientific method that invariably produces secure knowledge.

However, they "*believe that the consensus view has certain shortcomings and weaknesses*" (Irzik & Nola, 2011, p. 592). First, the image of science depicted is too restricted. There is no mention of the aims of science or methodological rules in science. It is not enough to say that there is no universal scientific method; it is needed to talk about methods and methodological rules in science to explain how science can be self-corrective and provide reliable knowledge. Second, they believe consensus view portrays a too monolithic picture of science, without consider differences among scientific disciplines (for example, astronomy and cosmology are different from, chemistry in that they are non-experimental disciplines). Finally, they raise the observation that the items seem to lack sufficient systematic unity (for example, if science is socially and culturally embedded, how is it that it produces knowledge that is valid across cultures and societies?).

Moreover, Irzik and Nola question the suitability of methodological approach used by the "consensus view" to define Science. The "consensus view" try to define Science, looking for a set of necessary and sufficient conditions. These conditions have to Science and all what is scientific. This approach perfectly suits in the case of "triangle", because its definition ("a closed plane figure with three straight sides") not only gives six characteristics which specify the necessary and sufficient conditions for being a triangle, but also determines the "essence" of being a triangle or the analytic meaning of the term "triangle". But, as Wittgenstein pointed out, this method cannot be used to define all terms (Wittgenstein 1958, sections 66–71), as, for example, "game". Its definition must include games as different as stick games, card games, ball games, children's games that do not involve balls, sticks or cards (such as tag or hide-and-seek), solo games (hop-scotch), mind games, and the like; and, unlike the case of "triangle", *"there is no fixed set of necessary and sufficient conditions which determine the meaning of game"* (Irzik &Nola, 2011, p. 594).

Irzik and Nola (2011) devise and improve (2014) a new NOS framework based on the Family Resemblance Approach (FRA) applied to Science definition, to make up for the shortcomings mentioned above and especially to solve the methodological problem of Science definition. The main idea of a family resemblance definition is that there is no one definition of it but a cluster of related notions, and each member of a family can resemble other members respect to some aspects, but not to others.

The authors explain how this approach works:

«Consider a set of four characteristics {A, B, C, D}. Then one could imagine four individual items which share some three of these characteristics taken together such as (A&B&C) or (B&C&D) or (A&B&D) or (A&C&D); that is, the various family resemblances are represented as four disjuncts of conjunctions of three properties chosen from the original set of characteristics. This example of a polythetic model of family resemblances can be generalised as follows. Consider any set S of n characteristics; then any individual is a member of the family if and only if it has all of the n characteristics of S, or any (n - 1) conjunction of characteristics of S, or any (n - 2) conjunction of characteristics of S, or any (n - 3) conjunction of characteristics of S, and so on. How large n may be and how small (n - x) may be is something that can be left open as befits the idea of a family resemblance which does not wish to impose arbitrary limits and leaves this to a "case by case" investigation» (Irzik & Nola, 2011, pp. 594-595).

Applying this approach, which was a philosophical idea made popular by Ludwig Wittgenstein, to NOS it is possible to create a family definition of Science, in which each member (scientific discipline) resemble to others for some aspects and differentiate for others.

A concrete example of how this approach is applied to scientific disciplines can be observed in Table 1.2. None of the four disciplines owns all the six characteristics, although they have in common several them. With respect to other characteristics, they partially overlap, like the members of closely related extended family. In short, taken altogether, they form a family resemblance.

Table 1.2. Example of Family Resemblance Approach ability of representing differences and similarities among disciplines (Irzik & Nola, 2014, p. 1015)

Characteristics / **Disciplines**	Data collection	Inference making	Experiment ation	Prediction	Hypothetic-deductive testing	Blinded randomised trials
Astronomy	x	x		x	x	
Particle physics	x	x	x	x	x	
Earthquake science	x	x		x'	x	
Medicine	x	x	x	x''		x
Using ' and '' we indicate differences in predictive power						

Using a Family Resemblance Approach (FRA) to NOS, it is possible to do justice to the differences that characterize the various scientific disciplines, while maintaining a systemic view to Science. However, the effectiveness of the approach depends on which categories are chosen to represent NOS, with respect to which scientific disciplines share or not some characteristics.

Irzik and Nola (2014) represent NOS as a cognitive-epistemic system, joined with a social-institutional system. The first system contains four categories: processes of inquiry, aims and values, methods and methodological rules, and scientific knowledge. The second, other four categories:

professional activities, knowledge certification and dissemination, scientific ethos, and social values. The analytical distinction in two system is useful to achieve conceptual clarity of NOS. But the authors underline that, in practice, it is present a constant interaction with each other in myriad of ways. In Table 1.3, the conceptualization of Nature of Science into two systems is schematized.

Table 1.3. Family resemblance approach (Irzik & Nola, 2014, p. 1009) – Adapted from Erduran & Dagher, (2014, p. 23)

Science							
Science as cognitive-epistemic system				Science as social-institutional system			
Process of inquiry	Aims and value	Methods and methodological rules	Scientific Knowledge	Professional activities	Scientific ethos	Social certification and dissemination of scientific knowledge	Social values

Summing up, we have seen that it is anything but easy to outline an approach to define the Nature of Science. The most used approach in science education, the consensus view, has been also questioned. An approach that avoids definitions in a classical sense (a set of necessary and sufficient characteristics) and seeks to be more comprehensive giving voice to the many aspects of Science is the FRA approach. In the next chapter I will report the perspective that was used as theoretical framework of the thesis, which starts from FRA of Irzik and Nola, but extends and reconceptualizes it, with particular attention to science education. The meaning of categories of NOS, and practical applications of that framework will be explained.

1.4. Reconceptualized Family Resemblance Approach to NOS

This paragraph is dedicated to illustrating the theoretical framework, used both as tool and guideline of the thesis: The Reconceptualized Family Resemblance Approach to NOS (RFN), by Erduran and Dagher (2014). At the beginning of my Erasmus Plus traineeship at Oxford, I have dedicated several times to the study of this framework, directly on the book that explain it, called "Reconceptualizing the Nature of Science for Science Education. Scientific Knowledge, Practices and Other Family Categories". Professor Sibel Erduran, one of the two authors, has been my trainee supervisor. I can say that to study on this book and could speak about it directly with the creator has been a very precious occasion of personal and academic enrichment.

In this paragraph, it would be impossible to describe all what is contained into the book, but, certainty, I will describe principal structure of RFN framework, underlining commonalities and differences, compared to Irzik and Nola's one, and its applications, I used in this thesis.

It is important to stress for clarity that, initially, the framework developed by Erduran and Dagher on 2014 was called simply "FRA to NOS". But, subsequently, the framework has been referred to as “Reconceptualised FRA to NOS” or RFN (Kaya & Erduran, 2016), in order to distinguish it from other philosophical interpretations of the FRA framework such as Irzik & Nola (2014) and the original work by Wittgenstein.

In the thesis, when I use “RFN”, I refer to the theoretical framework of Erduran and Dagher (2014); while I use “FRA” to the *family resemblance approach* used in RFN framework. Using “FRA categories” or “NOS categories”, I refer to the categories of Nature of Science established by Erduran and Dagher in RFN. In case I refer to other frameworks, as the one by Irzik and Nola, I will say it explicitly.

1.4.1. RFN main structure

RFN framework is based on FRA approach applied to Science, the same approach used by Irzik and Nola (2011; 2014). Erduran and Dagher (2014) have chosen FRA approach to NOS, because they strongly believe a “family resemblance” approach possesses appealing aspects. For example, it has the capability to unify together epistemic, cognitive and social aspects of science “in a wholesome, flexible, descriptive, but non-prescriptive way” (Erduran & Dagher, 2014, p. 24); it incorporates important existing NOS frameworks, “Consensus View” and “Feature of Science” (a detailed explanation about how FRA includes several aspects of these two frameworks is reported in table at page 26 of their book); it is more inclusive of various aspects of science, being potentially more appealing to a wide range of students (for example, some students could be attracted by epistemic aspects of science; others, by its social or institutional aspects).

Erduran and Dagher extended and modified the FRA framework by Irzik and Nola (2014), in order to keep the terminology clear and to build a framework organization closer to their NOS idea, particularly oriented to Science Education.

1.4.2. FRA wheel

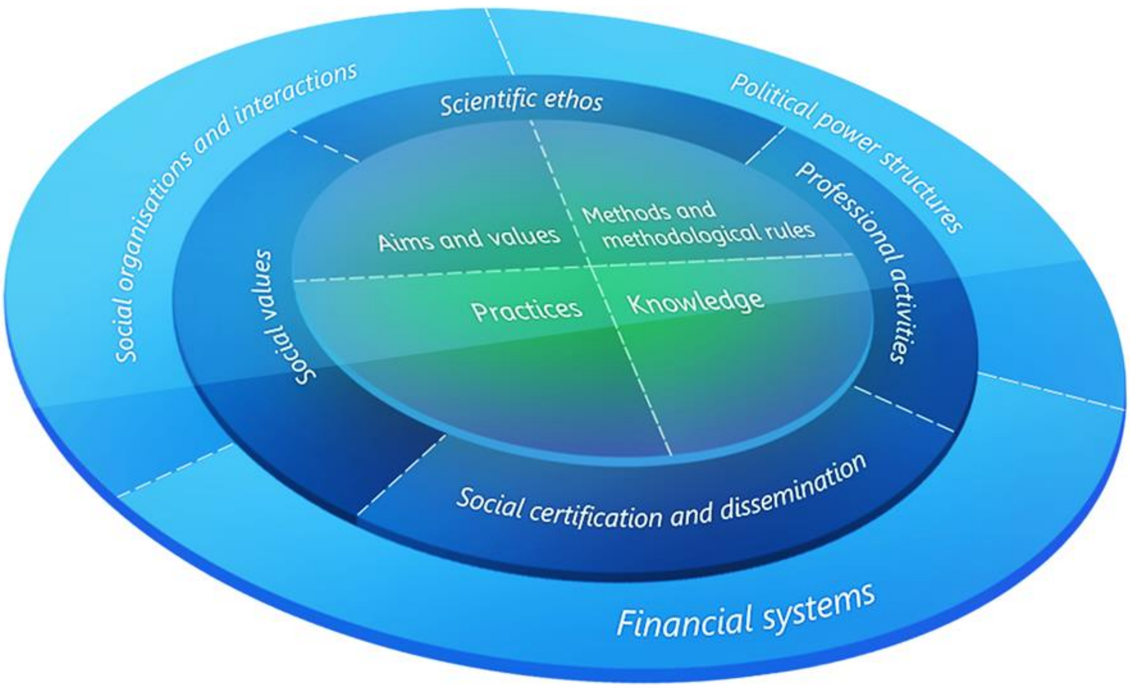
Erduran and Dagher represents NOS using the “FRA wheel”. According to Irzik and Nola (2011; 2014), NOS can be depicted as the union of two systems, cognitive-epistemic and social-institutional. FRA wheel is a visual representation of how these two systems interact together. An image of FRA wheel is provided in Figure 1.1.

At the centre of FRA wheel, it is represented the cognitive-epistemic system, made of four categories: Aims and values, Methods and methodological rules, Practices, and Knowledge. This system, represented as a circle, floats within a larger concentric one, that represents the social-institutional system of science. This second outer circle is also divided into four quadrants, each one containing a category: Social values, Scientific ethos, Professional activities, and Social certification and dissemination. Erduran and Dagher believes social-institutional aspects were limited in Irzik and Nola work (2014). For this reason, three more social-institutional categories were added to four initial categories: Social organizations and interactions, Political power structures, and Financial systems. The external circle of FRA wheel contains them.

The boundaries among both categories and systems are *porous*, allowing fluid movement across them. All comparts flow naturally in all directions. The meaning behind FRA wheel is that all categories of NOS interact with one another, influencing scientific activity.

The concentric shape intends to show a holistic and comprehensive Science, in which many elements dynamically interacts. The FRA wheel can be practically used in science education, as tool to show a larger image of NOS. Science teacher can use it when they intend to include in their lesson a more balanced and comprehensive account of NOS.

Figure 1.1. FRA wheel: science as a cognitive-epistemic and social-institutional system (Erduran & Dagher, 2014, p.28)



1.5. FRA categories of Science

In this subsection, cognitive-epistemic and social-institutional categories are explained.

Cognitive-epistemic categories of NOS:

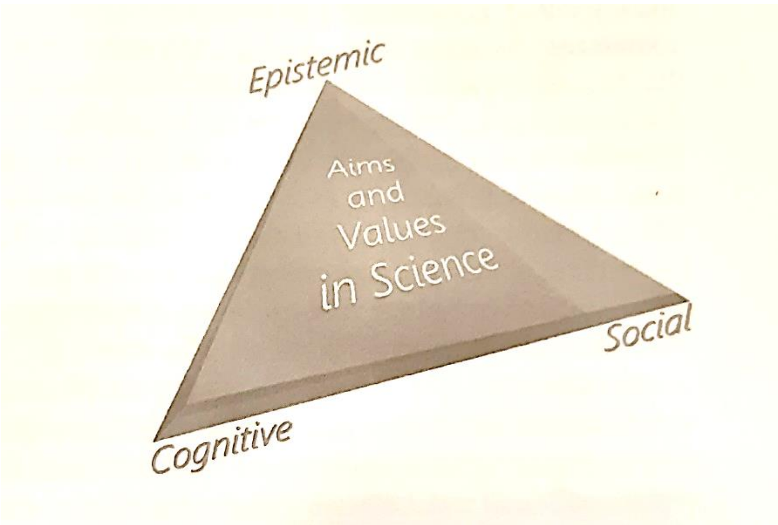
- **Aims and values:** Aims and values (A&V) are that set of aims that the products of science should fulfil. “It is difficult to provide a normative set of aims and values that would be exhaustive and representative" (Erduran & Dagher, 2014, p.48). The intention of RFN framework is not to provide an exhaustive summary of A&V, but to provide a toolkit which can be utilized by science educators to explore types, functions, and properties of A&V in science.

Types of A&V are epistemic and cognitive, in the sense that they characterize either the scientific knowledge or the forms of reasoning that stay behind science. Examples of epistemic and cognitive A&V are consistency, simplicity, objectivity, empirical adequacy and novelty. Others A&V of science are social, political, and cultural, like being free from inductive bias, honesty, applicability to human needs, decentralization of power with respect to race and gender.

A&V can have different roles, like to influence theory choice, impact on how scientists interact with their environments and affect methodological decisions and interpretations. In this sense, A&V "are about how to conduct scientific inquiry or how to understand scientific inquiry from holistic perspective" (Erduran & Dagher, 2014, p.49).

For science education, Erduran and Dagher (2014) underline the importance of creating and developing classroom cultures where the teacher and the students are explicitly aware of epistemic values, enabling them to have common language in approaching, conducting and interpreting scientific activities. As support for teachers, the authors suggest a framework (Figure 1.2), that summarized and visualized the key categories of A&V, represented as a corner of a tringle.

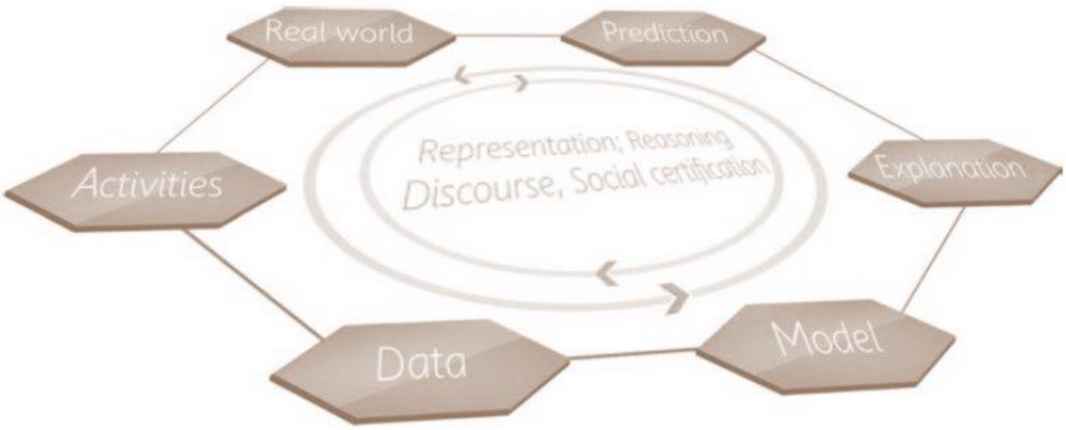
Figure 1.2. Aims and values in science (Erduran & Dagher, 2014, p. 49).



This figure signifies that epistemic, cognitive, and social aims and values in science are not easily distinguishable, but that the boundaries between them are continuous and blurry. In classroom, epistemic goals should be highlighted as relevant for knowledge construction, evaluation, and revision of practices; cognitive, as relevant for scientific reasoning; and social, as relevant to social aspects of science, as issues that involve human needs or honesty.

- **Scientific Practices:** first, Erduran and Dagher (2014) changed the terms “activities” and “processes”, adopted by Irzik and Nola (respectively, 2011; 2014) into “practices”, to align this category with those included in contemporary science education literature, as, for example, the American K-12 education standard (National Research Council, 2012).

Figure 1.3. Benzene Ring heuristic (Erduran & Dagher, 2014, p. 82)



They carefully explained the role of scientific practices and their meaning, starting from three human activities: classification, observation, and experimentation. Human activities, in the sense that they are not only scientific activities but are used also in other human fields. These activities have been emphasised in scientific curriculum for many years, but limitedly in terms of their epistemic framing. Therefore, there are usually less questions and discussion, in classroom, about how they do contribute to scientific knowledge. A scientific practice is not an isolated activity, but an activity that is influenced by aims and values of science; is aware of existing laws and theories; takes into consideration the economic or political possibilities of the scientific world of that moment. That is, it is completely infused by epistemic, cognitive, and social aspect of scientific environment.

Returning to the three activities above, observation become scientific practice when embedded in scientific theories and interlinked to other epistemic practices as modelling; classification is a practice, when it is driven by epistemic purposes, as for example the achievement of predictive power; experimentation is a scientific practice when it is not a predetermined set of actions, but the methodology is decided according to those available or to which data are collected or which knowledge is existing.

For science education, a pedagogic tool called Benzene Ring heuristic, useful for teaching about scientific practices, has been provided (Figure 1.3). It brings together the often-disparate components of science (as modelling and social certification) and aims to show a more nuanced and holistic representation of scientific practices. The authors explain it as follow: "*The heuristic illustrates the epistemic and the cognitive dimensions of science as being interrelated and influenced by social dimensions in one holistic representation. The links between the different epistemic components are underlined by dynamic socio-cognitive processes represented by the electron cloud denoting representation, reasoning, discourse and social certification (among other cognitive, social and institutional factors) which enable the instantiation of each component. The internal ring structure represents the 'cloud' of processes (including the sociological, cultural and economic dimensions) that underlie the epistemic components. The flow is multidirectional and fluid. A significant strength of heuristic is that the typically disparate science process skills are no longer isolated but a fundamental redefined and positioned in interactions within and relative to other scientific practices*" (Erduran & Dagher, 2014, p.82).

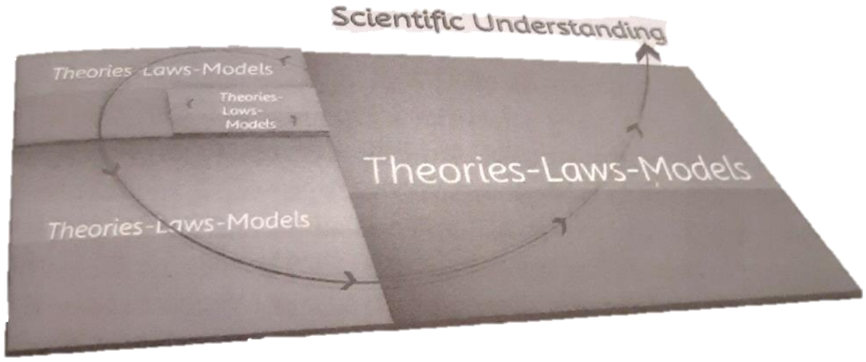
- **Methods and methodological rules:** they refer to the variety of systematic approaches that scientists use to ensure reliable knowledge. What Erduran and Dagher (2014) aim to do is to shift the focus of scientific education from the myth of the scientific method to a more articulated image, which captures the complexity and diversity of scientific methods and methodological rules.
- **Scientific knowledge:** Scientific knowledge refers to the "products" of scientific activity, as laws, theories, models, but also collections of observational reports and experimental data. The authors support the idea that theories, laws, and model work together in generating scientific explanations. This process led to knowledge growth. A visual representation of this theories, laws and models (TLM), working together to generate or validate new knowledge, is provided in Figure 1.4.

Social-institutional categories of NOS:

- **Professional activities:** this category refers to activities performed by scientists in order to communicate their research, such attending to meetings or writing manuscripts for publications and developing grant proposal to obtain funding.
- **Scientific ethos:** it refers to norms that scientists observe during their own work as disinterestedness and communalism, or ethical norms such as honesty and respect for research subjects and environment.

- **Social certification and dissemination:** this category refers to peer review process, a social quality control of scientists' work.
- **Social values of science:** it refers specifically to social values included into aims and values of science, as social utility, improvement of people's health and quality of life, and contributing to economic development of society.

Figure 1.4. TLM, growth of scientific knowledge and scientific understanding (Erduran & Dagher, 2014, p.115)



- **Social organizations and interactions:** this category refers to social organizations in which scientists work and meet, as universities and research centres. The nature of social interactions among members of a research team working on different projects is governed by an organizational hierarchy. In a wider organizational context, the institute of science has been linked to industry and the defence force.
- **Political power structures:** this category refers to all political environments that influence (positively but also negatively) the scientific enterprise. The authors believe it is extremely important in science education uncover the political heritage of science and actively promote a science that don not perpetuates a legacy of injustice.
- **Financial systems:** this category refers to the fact science lay on economic forces. Students should be aware that science is institutionalized system that is tied to economic factors.

An additional description of FRA categories can be found in Table 1.4. At the beginning of my RFN studies, I have looked at this table, to get an initial overview.

1.6. Final considerations

We have seen some NOS theoretical frameworks. In this thesis I have adopted RFN framework because of its holistic and comprehensive vision of NOS, its visual tools, useful for science education, and the possibility to study it close, collaborating with Professor Erduran. Moreover, RFN is considered a promising tool for teachers' and students' education on NOS, useful in classroom activities, and a framework for science curriculum analysis (Kaya et al. 2019; Yeh et al., 2019). All these reasons led me to choose it.

In this thesis project, RFN has been used as tool to investigate NOS presence into physics guidelines of Italian high schools. The eleven categories of NOS described by RFN (further summed up and explained in Table 1.4.) have oriented the analysis. After this analysis, I focused on practices category and I investigate how practices are present in physics classroom lessons. For this reason, a larger explanation about scientific practices (respect to other categories) was provided in the previous paragraph.

Table 1.4. FRA categories (from Erduran and Dagher 2014a) – adapted from Yeh et al, (2019, p. 295)

Cognitive-epistemic system 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 utilize 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 utilizing 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 conceptualized as a coherent network, not as discrete and disconnected fragments of knowledge.
Social-Institutional system 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 organized skepticism, 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, decentralizing power, honesty, addressing human needs, and equality of intellectual authority.
	Social organizations and interactions	Science is socially organized 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 organizational hierarchy. In a wider organizational 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 organizations have an influence on the types of scientific research funded, and ultimately conducted.

Chapter 2. Analysis of physics guidelines using RFN

During the traineeship at Oxford University with Professor Sibel Erduran (the supervisor) and Doctor Alison Cullinane (the tutor), I had not only the possibility to deepen the NOS, in science education field, and RFN framework, but also to develop a project with them. We decided to investigate the presence of NOS in physics guidelines of Italian high school, using the RFN framework. Professor Erduran and Doctor Cullinane have collaborated with me to this project, that represented for me a concrete occasion to improve my abilities regarding science education research. We are writing a research paper on the results we found in this project. Both the guidelines analysis and the practice of article writing have been great opportunities of academic training for me. In this chapter I will describe all project phases, final results and the methodological skills I have learned.

2.1. Aim of analysis

The project objective was to investigate the NOS presence in physics guidelines adopted in Italian upper secondary schools (study course attended by 14 to 19-aged students). In Italian school guidelines, there is no section solely dedicated to NOS teaching. Therefore, we decided to analyse the whole guidelines, to search for presence of NOS elements, included and considered necessary for physics learning by Italian science education polices.

2.2. Analysis phases

The analysis was articulated in two main parts: the first concerns the searching for FRA categories of NOS into physics guidelines; the second regards the searching for connections among FRA categories of NOS into Physics guidelines.

Before carrying out the effective analysis, some preparatory stages were performed: I have dealt with the choice of which physics guidelines to analyse (each type of Italian high school has its guidelines); the translation of guidelines text from Italian to English; the subdivision of text in smaller subsections; the decision of the methodological rules to follow in the analysis.

2.3. Preparatory stages

2.3.1. Choice of physics guidelines

I personally took care of the choice of the guidelines document to be analysed for some reasons: I had a direct experience with Italian schools (unlike my collaborators) and a greater ease in understanding Italian documents (being an Italian native speaker). The choice has been based on some factors:

- that the document referred to a physics course of upper secondary school, with duration as long-lasting as possible.
- that contents of physics guidelines were as complete as possible.
- that the type of school that adopts that guidelines is attended by many students.

It has been necessary to explore the Italian school system and policies, to collect useful information before the choice. The compulsory education for students in Italy, after lower secondary school graduation, provides two possible paths: the "scuola secondaria di secondo grado" (upper secondary school), that lasts five years, or the "istruzione e formazione professionale" (education and professional training), structured in either three or five years professional cycle of study. Leaving out the professional training, principally focused on teaching students a specific trade, the upper secondary school is itself divided into three possible paths: "Liceo", "Istituto tecnico" and "Istituto Professionale". In all these schools, students study physics, for at least one year. The school in which students attends the most numbers of hours of physics is called "Liceo Scientifico" translated as "Scientific High School" (MIUR, 2010a). This school provides cultural and methodological instruments to have a deep understanding of reality and develops logic, creative, rational and critical approaches to situations. Students acquire useful skills to continue the study at upper levels of education (e.g., university). Scientific High School offers three possible curricula of study, called respectively "Traditional", "Applied Sciences-oriented" and "Sport-oriented" (differences depend on how many weekly hours are dedicated to deepening Scientific or Sportive disciplines). Each year, thousands of students enrol in Italian upper secondary schools. A report shows that the number of application forms presented to the first class in 2019/2020 school year was 542654. In total, 94,7% of 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%). More specifically, 25% of students choose the "Liceo scientifico" (15,2% choose Traditional curriculum, 8,2% the Applied Sciences curriculum and 1,6% the Sport curriculum).

According to this analysis, I decided to analyse the physics guidelines adopted by the Scientific high school (MIUR, 2010b). The same guidelines (except for one different statement, I will indicate below as "G.8") are adopted also by Applied Sciences-oriented and Sport-oriented schools (MIUR, 2010b; MIUR, 2013). With this choice, our analysis covers almost a quarter of students that enrol in Italian high schools. Moreover, it concerns the richest and longest physics guidelines adopted in high schools, and, thus, we can consider these guidelines to be those that cover a greater and varied image of physics in high school.

2.3.2. Translation of the curriculum from Italian to English

To ensure an accurate translation of the document from Italian to English, several steps were undertaken. First, to do the bulk of the translation, an online translation tool called ReversoContext (https://context.reverso.net/traduzione/) was used to translate the document from Italian to English. Then, I created a Word file, made of two columns, in which, I have inputted the Italian text of guidelines in the first column, and the bulk of the English translation, in the second column. Reading both the Italian and English juxtaposed texts, I have done a first check of the translation. The reliability of this first check comes from the fact that I am Italian native speaker and students, used to read both Italian and English physics texts.

During the traineeship, I have learned that it is a good practice of research to always perform a second check by a second expert person. For this reason, in addition to my translation, the document was checked for accuracy by Italian colleagues, who were also proficient in the English language, and were well versed in reading and writing for both Italian and English in science and physics education academic audiences. They were able to confirm the translation and minor sentences were changed before the document was analysed.

2.3.3. Creation of the Analysis grid

The physics guidelines text are structured in four macro sections: first section regards the general guidelines (G), an overview among all 5-years of physics course, in which are described general objectives and skills to be achieved; the second, third and fourth sections are specific guidelines, that explain physics contents, themes and aspects the students should learn. The first specific section (S1) regards first two years of physics course; the second specific section (S2) concerns second two years of school, and the third section (S3) regards the last year of the physics course. These four sections have been further subdivided, because of the necessity to analyse smaller parts of text at a time. Each subsection is called with the letter and number (only for specific sections) of belonging section, followed by a progressive number, that identify the subsection. In total, eight subsections for general part and twenty-one for specific part have been created.

All guidelines subsections, with the corresponding name, have been inputted into a grid (on the left column). On the right, five empty columns, one per each cognitive-epistemic category (Aims and Values, Scientific Practices, Methods and Methodological Rules, Scientific Knowledge), and one for social-institutional categories, have been created. These columns had to be filled in during the analysis, only if a NOS category was present in the corresponding subsection. In Table 2.1., it is possible to see how the grid looks, at subsection number 3 of S1 section.

Table 2.1. Fragment of the analysis grid: subsection number 3, section S1.

		Cognitive-epistemic system				**Social-institutional system**
	SPECIFIC GUIDELINE AND SKILLS SECOND BIENNIUM	Aims and values	Scientific practices	Methods and methodolo gical rules	Scientific knowledge	
S1.3	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.					

In appendix A, all translated physics guidelines, subdivided in smaller subsections, and inputted into the grid, used for the analysis, are provided.

2.3.4. Methodological rules of analysis

Together with my supervisors, the methodological rules of analysis to follow have been decided. That was important because, in order to have reliable results, two separated analysis have to be performed by at least two independent researchers. And it is necessary that both follow the same methodological rules, to produce comparable results.

The rules we decided are:

1. When a NOS category of cognitive-epistemic system is recognised into a subsection text, an affirmative mark is filled in the corresponding cell.
2. When a NOS category of social-institutional system is recognised into a subsection text, an affirmative mark is filled in the corresponding cell, together with the name of the category.
3. More than one category can be recognised into a subsection text.
4. If the same NOS category is recognised into a subsection more than once, that category must be marked just once.
5. To remember what part of the text is referred to a NOS category, it should be underlined, and a reference should be added next to it.

2.4. Analysis of FRA categories of NOS into physics guidelines

2.4.1. Analysis and reliability

Following the methodological rules, two independent physics guidelines analysis have been performed. An example of filled grid is showed in Table 2.2. It is showed that, in section S3.6, more than one FRA category was found: the e*xperimental dimension* of physics falls under the Method and Methodological rules category; *activities in didactic laboratory* under the Scientific Practices category; *universities and research institutes laboratories* relate to Social organization and interactions category. The mentioned categories have been filled with a mark and a reference, to remember which part of the text is related with the corresponding categories.

Table 2.2. Example of physics guidelines analysis

		Cognitive-epistemic system				**Social-institutional system**
	SPECIFIC LEARNING OBJECTIVES FIFTH YEAR	Aims and values	Scientific practices	Methods and methodological rules	Scientific knowledge	
S3.6	The experimental dimension (B) can be further deepened with activities (A) to be carried out not only in the school didactic laboratory, but also in universities and research institutes laboratories (C), also adhering to orientation projects.		•A	•B		•C Social organization and interactions

After this round of analysis, percentage agreement was calculated by using a method put forward by Miles and Huberman (1994). One (1) was recorded when there was a match in the categorisation, and a zero (0) was recorded when there was a disagreement in the categorization process. All these matching instances (ones) were counted and divided by the total number of instances recorded. According to their methods, Miles and Huberman (1994) suggest that a percentage agreement over 80 percent is a good indicator of reasonable reliability.

$$\text{percentage agreement} = \frac{\text{number of matched categorizations}}{\text{total number of instances recorded}} \times 100$$

In the first analysis, 58 instances were found, and, in the second, 35. The number of times that the same category was recorded, was 30, versus a disagree categorizations of 34. The percentage of agreement resulted 46.9%.

The most interesting part of the analysis, that I called “phase of reconciliation”, has been done subsequently. This phase consists in a discussion between the assessors who made the analysis, in which all subsections have been examined, saying the reasons why a certain categorization has been done. After debating, both had the opportunity to re-do their categorization or maintain the previous one.

After this “reconciliation”, the NOS categories found by the first analyser decreased from 58 to 49, although the other increased his instances from 35 to 47. All results, category per category, are showed in Table 4. A new percentage agreement has been calculated: having 44 overlapping instances of agreement and eight instances of disagreement, the overall percentage agreement was found to be 84.6%. As regards the individual NOS categories, the percentage agreements were always over 80%, except for "social value of science" and "financial system". In these categories, the low number of categorizations registered and only one time of disagreement generated low levels of percentage agreement.

Table 2.3. FRA categories found in physics guidelines analysis (matched and unmatched categorizations, and percentage of agreement).

	Cognitive-epistemic				**Social institutional**							**Tot**
FRA Categories	Aims and values	Scientific practices	Methods and methodological rules	Scientific Knowledge	Professional activities	Scientific ethos	Social certifications and dissemination	Social values of science	Social organizations	Political power structures	Financial systems	
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 per category (%)	100	83.3	88.9	86.4	-	-	100	50	100	-	0	
Percentage agreement 84.6%												

2.4.2. Results

The results, reported in Table 2.4, regarding the union of both assessors' results, include the eight NOS disagreed categorizations and the forty-four agreed. The results in Table 2.4. are represented as coloured cells. Even if all results have been included, we wanted to distinguish the agreed categorizations (blue) from the disagreed ones (brown), to focus more on shared NOS aspects found in the physics guidelines, when we will see the details.

The results show that 52 instances of NOS were found into physics guidelines. Only 6 (11.5%) on the total were related to social-institutional categories of NOS. That is immediately visible, looking at the low density of coloured cells on the right side of Table 2.4., concerning precisely social-institutional system of NOS. While, on the left, at least one category (concerning cognitive-epistemic system of NOS) is found per each subsection of guidelines, except for "G7". Starting from the most popular, the guidelines has several instances related to the "Knowledge" category (22 instances in total), followed by "Practices" (12), then "Methods and methodological rules" (9), and then "Aims and values" (3). The instances from the social-institutional aspect belong to "Social certification and dissemination" (1), "Social values of science" (2), "Social organisations and interactions" (2) and "Financial systems" (1). Some social-institutional categories are totally absent in the physics guidelines. It is about "Professional activities", "Scientific ethos", and "Political power structures".

Table 2.4. NOS elements detected in physics guidelines. The blue cells refer to agreed categorizations; the red cells refer to disagreed categorizations. In line "Agreed", the number of agreed categorizations found, of a certain NOS category, is reported; in line "Total", the number of all categorizations found, of a certain NOS category is reported.

	Cognitive-epistemic system				**Social and institutional system**						
	Aims and values	Scientific practices	Methods and methodological rules	Scientific Knowledge	Professional activities	Scientific ethos	Social certifications and dissemination	Social values of science	Social organizations	Political power structures	Financial systems
G.1	blue			blue							
G.2		blue	blue								
G.3		blue									
G.4		blue									
G.5	blue	red	blue	blue							
G.6		red						blue			red
G.7									blue		
G.8		blue	blue	blue							
S1.1		blue		red							
S1.2		blue	blue	red							
S1.3		blue		blue							
S1.4			red	blue							
S1.5				blue							
S1.6				blue							
S1.7			blue								
S2.1	blue	blue		blue							
S2.2		blue	blue	red							
S2.3				blue							
S2.4				blue			blue				
S2.5				blue							
S2.6				blue							
S2.7				blue							
S3.1				blue							
S3.2				blue							
S3.3				blue							
S3.4				blue							
S3.5			blue	blue							
S3.6		blue	blue						blue		
S3.7				blue				red			

Agreed	3	10	8	19	0	0	1	1	2	0	0
Total	3	12	9	22	0	0	1	2	2	0	1

A comparison between general and specific parts of physics guidelines (Table 2.5.) shows that the guidelines authors stressed the importance of "Scientific Practices" of physics in general part (6 instances found), but it is "Knowledge" of physics that builds the central structure of guidelines, in specific part (19 instances found). Below, an overview of two parts is provided, detailing only shared aspects of categorization.

Table 2.5. Comparison of NOS categories found in the general (G) and specific (S) part of the physics guidelines. In both general and specific part two level of results are shown: "All results" refers to all categorizations found in that part of guidelines by at least one assessor; "only agreed" refers to all shared categorizations found in that part of guidelines. In the last row, all categorizations found in the whole guidelines are reported. In general part, "Scientific practices" is the NOS category more present; in specific part, "Scientific knowledge" is the NOS category more present.

Guidelines Parts \ FRA Categories		Cognitive-epistemic				Social institutional						
		Aims and values	Scientific practices	Methods and methodological rules	Scientific Knowledge	Professional activities	Scientific ethos	Social certifications and dissemination	Social values of science	Social organizations	Political power structures	Financial systems
General part	All results	2	6	3	3	0	0	0	1	1	0	1
	Only agreed	2	4	3	3	0	0	0	1	1	0	0
Specific part	All results	1	6	6	19	0	0	1	1	1	0	0
	Only Agreed	1	6	5	16	0	0	1	0	1	0	0
Total		3	12	9	22	0	0	1	2	2	0	1

In the general part, the physics guidelines developers promote student's skills regarding physics, through practices like observing and identifying phenomena (subsection G.2); formulating explanatory hypothesis, using models, analogies and laws (G.3); formalising a physical problem, using correct mathematical tools (G.4); experience various practices related to experimental methods (G.8). There is the intention to bring students closer to aspects of aims and values of physics, such as the cognitive values of the discipline (G.1), the reliability of scientific methods (G.5) and the understanding of the inductive nature of the discipline (G.8). In these last two cases, reading the text of guidelines, the intention does not explicitly emerge, to be caught by all teachers, but there are only brief mentions. Regarding the category of methods and methodological rules, there is a prominence for the experimental method of physics (G.2 and G.5) and the role of laboratory (G.8). During the course, the students should experience and be able to explain the meaning of aspects of the experimental method. Some ways to achieve this are suggested: the choice of significant variables; the critical collections and analysis of data; the critical analysis of the reliability of measurement process; the model construction and validation (G.5). Regarding the social-institutional aspects of physics, students should "become aware the link between the development of physical knowledge and the historical and philosophical context in which it evolved" (G.1), "understand scientific and technological choice that affect the society in which they live" (G.6), and the collaboration between school and universities and research centres should be promoted (G.7), but the modality are left to teacher sensibility.

In the specific part of the guidelines, the general objectives are contextualized, but not always it is explained how to concretely achieve them. There is a predominant focus on students' understanding of "knowledge" of physics, that is laws, concepts, and theories regarding various physics fields (geometric optics in S1.3; mechanics in S1.5; thermodynamics in S1.4 and S2.5; work and energy concepts in S1.6 and S2.4; gravitation in S2.4; waves in S2.6 and S3.2; electromagnetism S2.7 and S3.1; special relativity in S3.5; quantum physics in S3.5) and language of physics (S1.1). A consistent attention is given to practices and methods of physics (respectively, 6 and 5 agreed instances found). For example, reference is made to the practice of simplifying and modelling real situations, to solve problems (S1.1); writing of reports (S1.2); through the study of geometric optics, interpreting the phenomena of light (S1.3); formulating problems (S2.1); through the experimental activity, discussing and constructing concepts, designing and conducting observations and measures, comparing experiments and theories (S2.2). Regarding methods and methodological rules, reference is often made to generic laboratory experiments (S1.2, S1.7, S2.2) and the utility of experimental evidence for building a special relativity theory (S3.5). Unfortunately, no aims and values are contextualised in the specific part of physics guidelines. There is only a mention to underline the quantitative and predictive nature of physical laws (S2.1), without better explaining how. About social-institutional aspects of physics, no refence is given in the first two years of course. Whereas there is an implicit reference to the social certifications of knowledge in the second two years of physics course (S2.4); in the last year, there is a suggestion to try laboratory experiences also inside universities or research centres, exploiting the orientation projects created by the universities (S3.6). I believe that is a good way to familiarize with the organization of scientific enterprises.

The references to social-institutional aspects and to aims and values of the discipline into the specific guidelines are weak. Regarding the first two-years of course (also called "biennium"), these references are completely absent, and this is negative. The basis of physics understanding should be built over the first two-year of course and this lack can lead students to have a limited idea of physics. By including these aspects in the guidelines, teachers would be encouraged to include or at least mention them to students. For the last three years of physics course (called “triennium”), these aspects are weakly present, noticing that the ways to concretely implement them are not very explicit.

Comparing these results to other studies on science guidelines in Ireland (Erduran and Dagher 2014b), in Turkey (Kaya et al, 2019), in Taiwan (Yeh et al 2019) and Hong Kong (Cheung, 2020), all have reported this particular imbalance (high density of categorizations in cognitive-epistemic system in contrast to low in social-institutional). Thus, the lack of extended attention to the social-institutional elements is not surprising as many curricula about the globe have the same features (Park *et al.*, 2020). However, the table shows a rather limited scope of the curriculum in terms of NOS representation and opportunities. As expected, the knowledge category has many instances, followed by the methods and practices categories. Unfortunately, the curriculum presents a narrow scope of science as a social institutional system aspect, with only six record instances, in total.

2.5. Analysis of connections among NOS categories into guidelines

2.5.1. Objective and methods of analysis

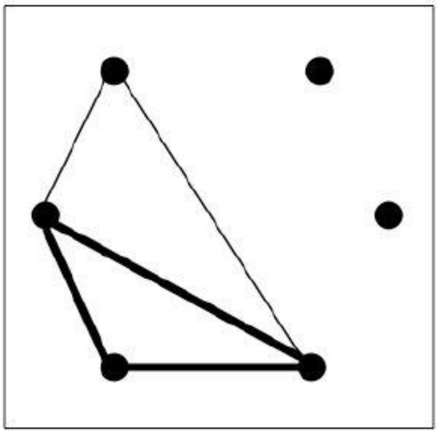
The objective of this analysis is investigating and visualizing the connections among NOS categories, found in the previous analysis of the physics guidelines. For this purpose, it was decided to perform an Epistemic Network Analysis (ENA). The ENA is described as an innovative approach to displaying the connections between data in a graphic image. It 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. Considering the NOS categories as our fixed elements, using the ENA, it is possible to generate the images that depict the connections among NOS categories found into the physics guidelines.

We produced the ENA analysis, using the Online ENA Tool[2], 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.

[2] Online ENA Tool, available at page www.app.epistemicnetwork.org

Mainly, the ENA tool works as follows: as input, it is needed the dataset, containing the data. Each column corresponds to each fixed element to analyse and each row corresponds to each section analysed. It is possible add more columns, to specify some useful characteristics of data. The dataset cells are filled with a one (1), when a certain fixed element has been found in a certain section. If not, they are filled with a zero (0). The ENA tool associates the "1" to the presence of a fixed elements. Every time that more than one "1" is found in a section, a connection is created among these elements.

Figure 2.1. Example of ENA result: the dots are the fixed elements, the lines are the connections among the elements (thicker means more frequent, thinner means less frequent)



In Figure 2.1. a simple example of ENA result is shown. This tool lead to understand immediately results, because it shows the most frequent connections as thicker lines among elements, and the more the frequency is low, the thinner the lines are.

2.5.2. Dataset for ENA analysis

In Table 2.6. some rows of the dataset we used for the ENA analysis are reported. We were intentioned to analyse which NOS categories coexisted in the same subsections of physics guidelines. For this reason, the dataset contains the fixed elements that are the NOS categories, and the sections of analysis that are the subsections of the document. There are additional columns, one to indicate the assessor of the analysis of the guidelines, and one to specify the section to which each sub-section belongs. This additional information was useful to perform better analysis.

Giving an example to better understand our dataset, the subsection 1.3, that belongs to the "S1" section of the guidelines document, has been analysed by the author "A, and he/she find two elements of NOS (Scientific Practices and Scientific Knowledge).

Table 2.6. Dataset used for ENA analysis of NOS categories into physics guidelines.

Document part	Assessor	Subsection	C E a & v	C E sc prac	C E meth ods & m rul	C E sc know	S I profes act	S I sc ethos	S I s cert & diss	S I s value of sc	S I s organ & inter	S I politic	S I financ system
G	A	G_1	1	0	0	1	0	0	0	0	0	0	0
G	A	G_2	0	1	1	0	0	0	0	0	0	0	0
G	A	G_3	0	1	0	0	0	0	0	0	0	0	0
…	…	…											
S1	A	1_3	0	1	0	1	0	0	0	0	0	0	0
S1	A	1_4	0	0	1	1	0	0	0	0	0	0	0
…													
S2	B	2_4	0	0	0	1	0	0	1	0	0	0	0
S2	B	2_5	0	0	0	1	0	0	0	0	0	0	0
…													
S3	Tot	3_5	0	0	1	1	0	0	0	0	0	0	0
S3	Tot	3_6	0	1	1	0	0	0	0	0	1	0	0
S3	Tot	3_7	0	0	0	1	0	0	0	1	0	0	0

2.5.3.ENA results of NOS categories into physics guidelines

Various analysis of the interactions between the NOS categories in the physics guidelines of “Liceo Scientifico” high school were conducted, each one useful for highlighting certain characteristics. The first analysis gives us the overall picture of the interactions found in the entire document; the second compares the connections of the general (G) and the specific part (S = S1 + S2 + S3) of guidelines; the third unpacks the specific part (S) in the first two years (called Biennium) and the last three years (called Triennium) of the physics course, comparing them and highlighting any structural differences.

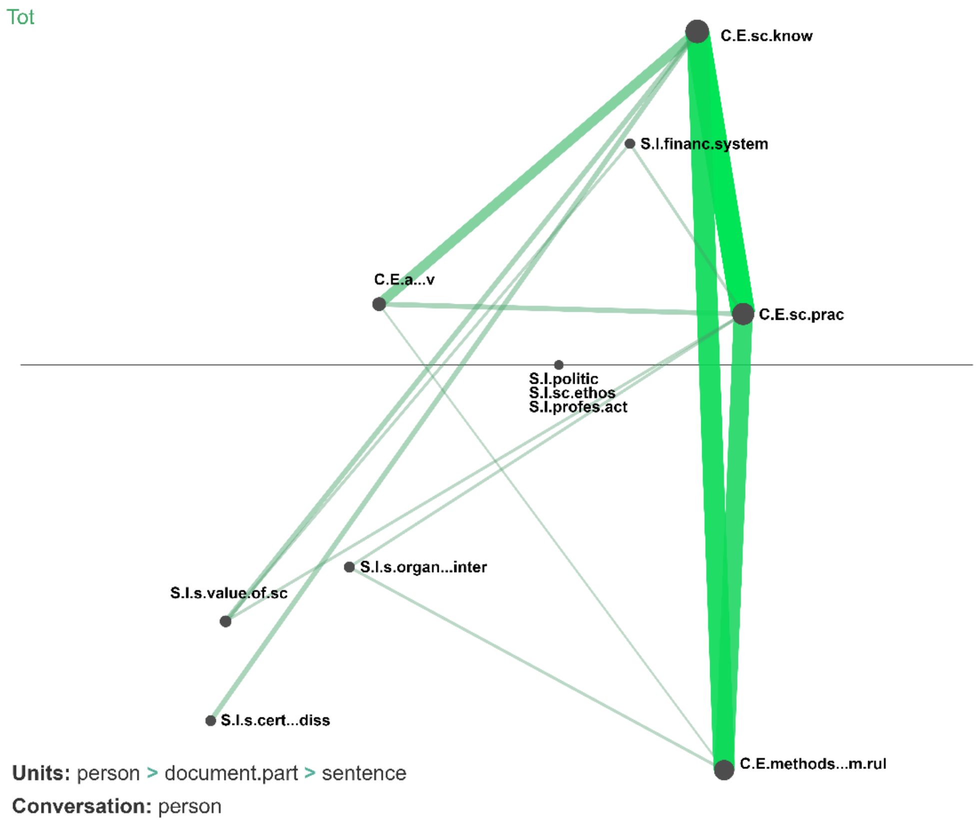
It is necessary to remember that the Online ENA tool, used to carry out the ENA analysis, creates connections, based on the zeros and ones read in the inputted dataset. It may happen that the assessors found two or more NOS categories in the same subsection either because these are casually described in the same sentence (without having a real logical connection between them), or because there is a real relations among them. The tool does not know how to discriminate this. For this reason, the analysis was useful to point out the structure of the connections and indicate where we could look for information into the documents. The real analysis has been done in the aftermath, verifying which were effective connections. Below, it is reported what we have observed.

- **The total connections between the NOS categories**

  The connections found in the whole guidelines are depicted in the image of Figure 2.2. Three elements (“political power structures”, “scientific ethos”, “professional activities”, belonging to the social and institutional system of science) are without connections among the others.

Three connections are prevalent: the connection among “scientific practices” and “scientific knowledge”; among “scientific practices” and “method and methodological rules”; among “scientific knowledge” and “method and methodological rules”. It is interesting to point out that all those are categories relate to the cognitive-epistemic system of Science.

Figure 2.2. Connections among NOS categories found in the whole guidelines document



- **The comparison of connections of general and specific part of guidelines**

  The general section G (Figure 2.3.) is characterised by an articulate range of connections that link both NOS categories within the cognitive-epistemic and social-institutional systems, and categories between the two systems.

  - Looking at Figure 2.3., the more frequent connections are between cognitive-epistemic categories of NOS. Between “practices” and “method and methodological rules” a connection is recognised in statement like “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 this case, it is explicitly suggested to explore and understand experimental methods of physics, through practices like the critical analysis of data.

Figure 2.3. Connections found in general part of guidelines

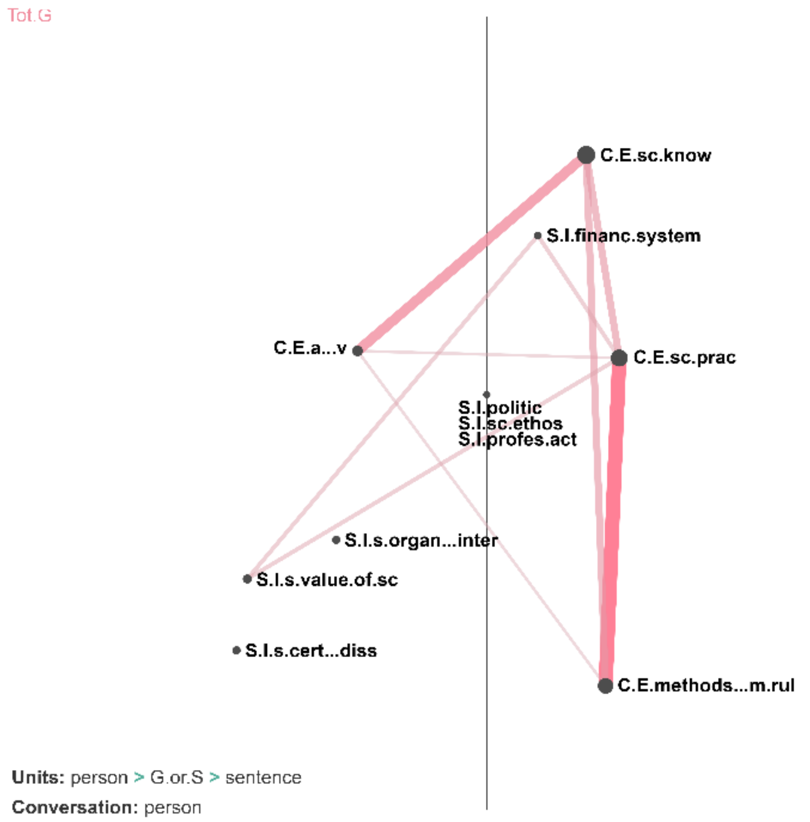
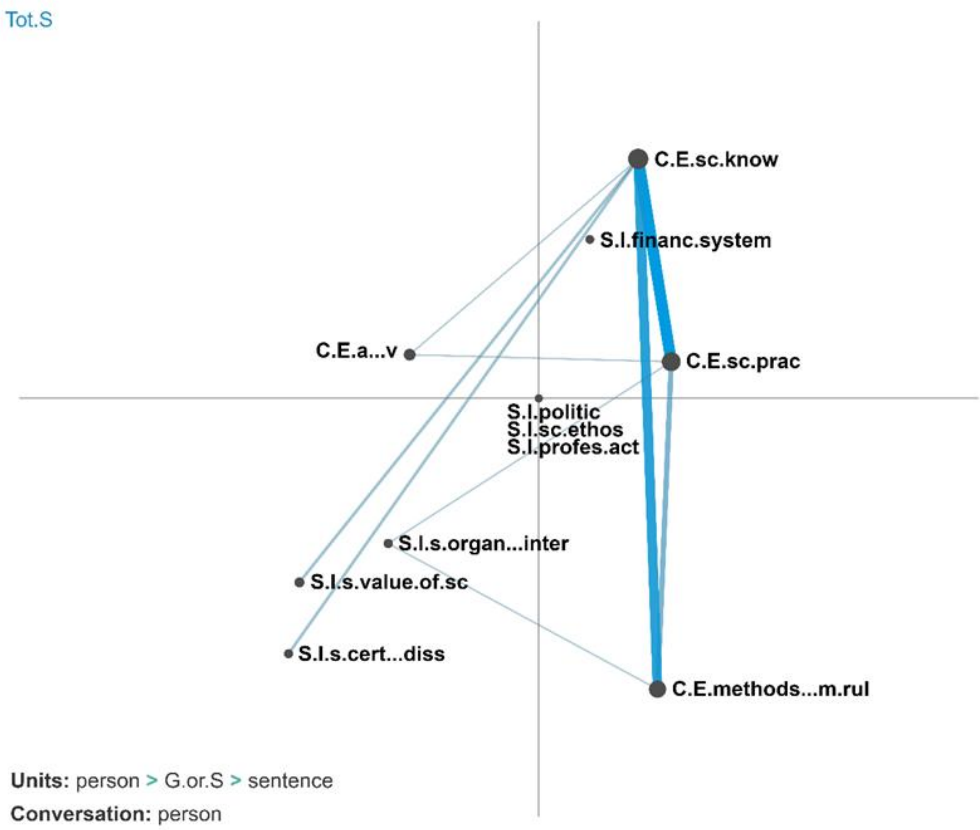


Figure 2.4. Connections found in specific part of guidelines



- Another important type of connections exists between “aims and values” and “knowledge”. This connection emerges explicitly in 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 to reason on the fact that the model to be valid must satisfy certain values that make it scientific.
- Other connections regarding “knowledge” and “practices” categories were found. For example, the document includes statements like “the activities and experience of laboratory gain a concrete perception of the connection between experimental evidence and theoretical models” (G.8). According to the RFN model, we analysed this claim as follows: theoretical models are products of science and deeply characterize the scientific knowledge. In the previous articulated claim, they emerge from the practice of laboratory that, hence, binds experimental evidence to the result of the practices, that is knowledge.
- A connection among “social value” and “practices” is recognised in statement like “the students will acquire the skills of understanding and evaluating the scientific and technological choices that affect the society” (G.6). In this case, cognitive practices as “understanding and evaluating choices” can allow the students to touch social values. However, this connection in not completely explicit.
- A connection among three categories, “aims and values”, “methods”, and “practices” exist when we speak about “the critical analysis of reliability of the measurement process “ (G.5), because methodological aspects of physics (“measurement process”) emerge as linked to a value (“reliability”), achievable through physics practices (“critical analysis”).

That was the detailed descriptions of connections (some more explicit, other less) found in the generic prat of the guidelines. Looking at the figure 2.4, regarding the connections in the specific part of guidelines (S), some structural differences immediately emerge: the connections are more frequently found among cognitive-epistemic categories, and the “knowledge” seems the main node of the links. From the previous analysis, in which we have investigated the presence of NOS elements in the guidelines, it emerged that the central role of the specific guidelines was delegated to the “knowledge”. Also, in this case, it seems that the “knowledge” is the fulcrum of the links between the NOS aspects of physics.

- In subsection S1.2 there is a link between the language of physics (which is a product of physics, therefore knowledge) and the laboratory experiments (practices), saying that he second should reinforce the first. An opposite case, namely that knowledge reinforces practices, is found in statement like “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" (S1.4). In this case, geometric optics is knowledge, and interpreting phenomena is practice.

- Some positive (in terms of variety of NOS explored) connections found are between "aims and values" and "knowledge", in statements like "the quantitative and predictive nature of physical laws" (S2.1). In this case, two values of physics knowledge are explicitly mentioned.
- Between "practices", "methods" and "social organizations" of physics, promoting moments of direct encounter with universities and research centres (S3.6). The direct meeting with universities, research centres and physicists can allow students to discover new scientific methods and practices. However, in guidelines, this connection is not so explicit.
- between "knowledge" and "social certification and dissemination", when it is suggested to analysing in detail the debate on cosmological systems, also in relation to history and philosophy (S2.4). The word "debate" can suggest a reference to the complexity of scientific theory certification. However, we believe that this connection is also not very explicit.

1. **The comparison of connections of "biennium" and "triennium" of guidelines**

This analysis compared the connections found in the specific part of the guidelines, dividing and showing, on one hand, the connections of the first two years of physics course (called biennium), and, on the other hand, the last three years of course (called triennium). We see the results respectively in Figure 2.5. and Figure 2.6. A strong structural difference between biennium and triennium is immediately visible. In the biennium, there are no connections, that involve the social-institutional aspects of physics and "aims and values". There are only connections between "knowledge", and "practices" and "methods and methodological rules".

Instead, during the last three years, there are varied and rich connections (twelve connections), almost all of them between "knowledge" and another NOS category. However, we should realize that these connections are often weak. If we exclude connections that involve disagreed categorizations, and the connections too implicit, few connections remain (one in S2.1 between aims and knowledge; one in S2.2, between methods, practices and knowledge; one in S2.4, between knowledge and social certification), leaving an image very similar to Figure 2.5.

Figure 2.6. Connections in the first two years of specific guidelines

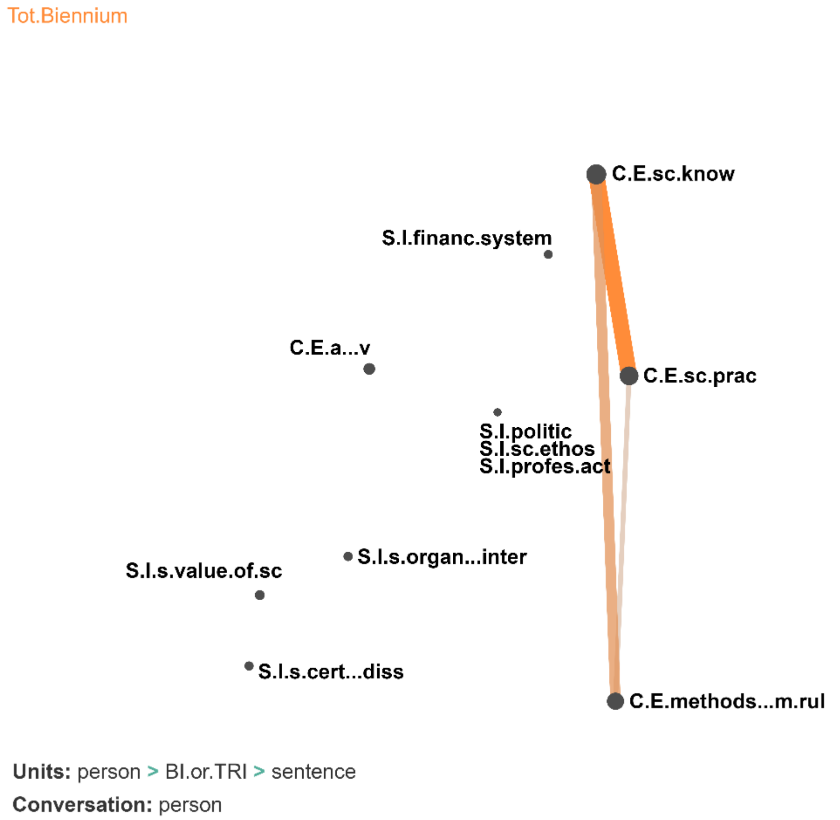
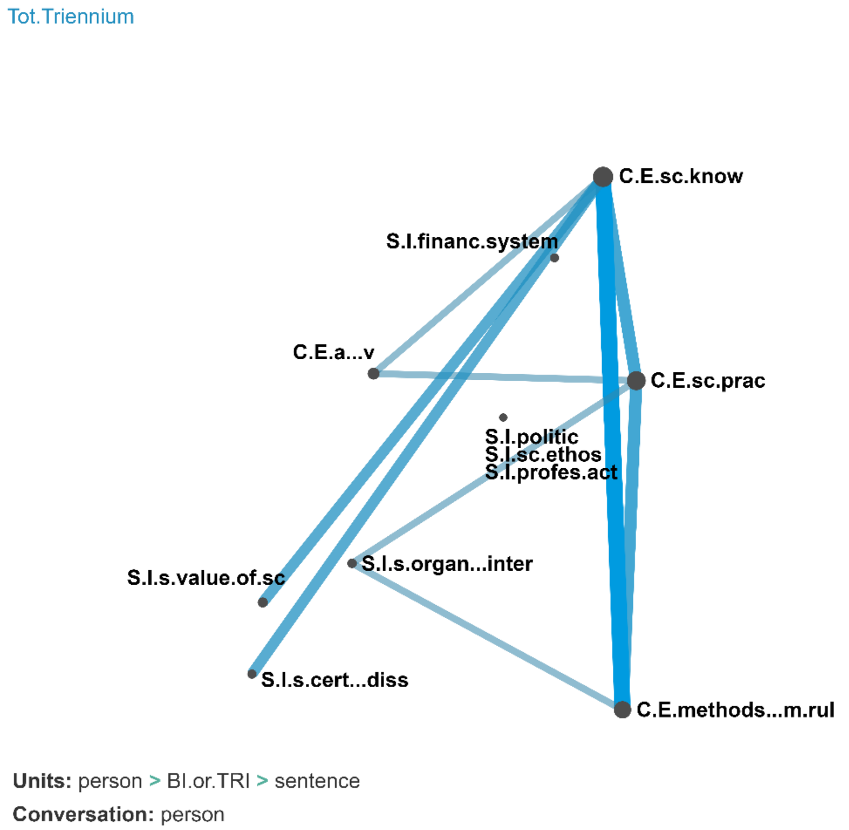


Figure 2.5. Connections in the last three years of specific guidelines



2.5.4. Conclusions

The ENA analysis allowed us to analyse the structure of connections between NOS elements into physics guidelines. The results have showed interesting aspects such as the fact that within the guidelines connections between the NOS categories can be found, apart from “professional activities”, “political power structures”, and “scientific ethos”, all belonging to social-institutional system of science.

The Covid era emphasized the importance of the relationship between science and the society. For this reason, it is extremely important that the relationship among NOS categories, especially the social-institutional ones, emerges also from the scientific guidelines adopted in high schools; and the lack, highlighted in the ENA analysis, becomes particularly problematic, in this historical period.

Another interesting aspect is the difference in the structures of the connections within the different parts of the curriculum. The part related to the general aims of guidelines covers many possible connections, prevailing between cognitive-epistemic categories of NOS. On the contrary, a more “pyramidal” structure, in which knowledge represents the main node of the connections, characterizes the specific guidelines. In particular, in the biennium, the only connections are between this main node and other two cognitive-epistemic categories, “practices” and “methods and methodological rules”. In specific guidelines of triennium, a more varied set of connections are found, but often too weak or implicit.

This structural difference seems to highlight a strong difference that is usually perceived by teachers and researchers: a gap between the intentions of a curriculum and the description of the contents that tend to stay rather traditional, also in their description, and weakly informed by NOS.

Our results resonates to other studies, that used the ENA analysis to look at curricula and assessments, finding that the NOS categories in relation to the social-institutional system are less prominent and are often not emphasised in the curriculum content (see the work of Cheung 2020 who analysed both the Hong Kong curriculum and assessments). To highlight the presence of, and the connections between, FRA categories, like “social organizations and interactions,” “political power structures,” and “financial systems”, in school guidelines would be really significant to students understanding of how scientific enterprises work within social and cultural milieu (Erduran and Dagher 2014). Nevertheless, the results from this analysis as well as studies by Cheung 2020, Yeh et al. 2019 and Park et al. 2020, highlighted an insufficient presence, articulation and interconnections among these categories.

Chapter 3. Interviews to physics teacher about Scientific Practices

3.1. Objectives of analysis

After analysing NOS presence into physics guidelines of Italian high school, a second analysis on NOS, from a different perspective, has been conducted: the teaching of NOS in physics classrooms according to the teachers' point of view.

This analysis is focused on one element of NOS, the scientific practices, and its aim is to deepen aspects like:

- how and when teachers, independently of the curriculum insert and address epistemic and cognitive scientific practices during the lessons?
- do textbooks help teachers in dealing with physics practices?
- what importance do the teachers ascribe to practices of Physics for their students?

The principal aim was to listen and analyse the point of view of the teachers, to understand what happens in practice when it comes to teaching the NOS in the physics classrooms.

3.2.What we mean by scientific practices

In paragraph 1.5, it has been shown an overview of FRA categories of NOS, according to RFN. As far as the scientific practices are concerned, it can be useful to resume the meaning of this category of NOS.

Erduran and Dagher (2014), RFN authors, have underlined that the main emphasis in science curriculum was given to science-as-knowledge until 1970s. A problem associated with this type of emphasis is that students risk to learn knowledge in a disconnected fashion, without comprehending the relations between different forms of knowledge, how knowledge grows, and which criteria drive growth of science. For this reason, the attention to scientific practices in science education has been increased since 1970s:

«Science cannot be viewed merely as a body of knowledge but rather as a particular epistemic, social and cultural practice». (p. 68)

According to this perspective, teaching scientific practices is supposed to allow students to understand how knowledge is built. However, it is essential to know that scientific practices are not simple human activities but epistemic entities, and that, very often, scientific curricula do not emphasise this fundamental characteristic of scientific practices enough:

«Science curricula place considerable emphasis on classification, observation and experimentation. Yet, these activities tend to be rather limited in terms of their epistemic framing. [...] Construing

scientific activities as practices means understand how scientific activities become epistemic entities, contributing to the generation and evaluation of scientific knowledge» (p. 68 and p. 71).

Below, it is explained when activities like classification, observation and experimentation (that are human activities, not only scientific activities) are intended to be scientific practices:

- **Classification**: scientists use classification not only to organize existing relationships but also predict new ones all the while operating within a broader theoretical framework.
- **Observation**: when embedded in scientific theories and interlinked to others epistemic practices as modeling, observation become a scientific practice.
- **Experimentation**: in science is not about predetermined set of procedures. What needs to be reproducible has to be specified. There is the use of epistemic criteria and standards.

Scientific practices do not involve only the epistemic dimension of science, but also cognitive and social dimensions. During a lesson of the academic course called "Advanced Professional and Research Skills in Physical Sciences", organized by the master degree in Physics of University of Bolgona, I had the opportunity to illustrate to my classmates the studies I was doing about scientific practices. During that meeting, I have asked them to reflect together about which dimensions of science are encountered in scientific practices. Starting from a list of twelve different practices and comparing different opinions, we conclude that each practice could involve more than one dimension of science. The result is shown in the Table 3.1.

Table 3.1. Results of debate about dimensions of science involve in scientific practices

Dimensions of science: epistemic (E), cognitive (C), social (S).			
MODELING	E	REASONING	C
MAKING PREDICTION	E	ASKING QUESTIONS	C, S
EXPLAINING	E	REPRESENTING/ DRAWING	C
ARGUING	E, C, S	MEASURING	E
CRITIQUING	C, S	ANALYSING DATA	E
CERTIFYING	S		

In paragraph 1.5, the heuristic of scientific practices, proposed by Erduran and Dagher has been provided. That heuristic is a visual tool, that synthesizes the theoretical account of scientific practices, making an analogy with the chemical Benzene Ring.

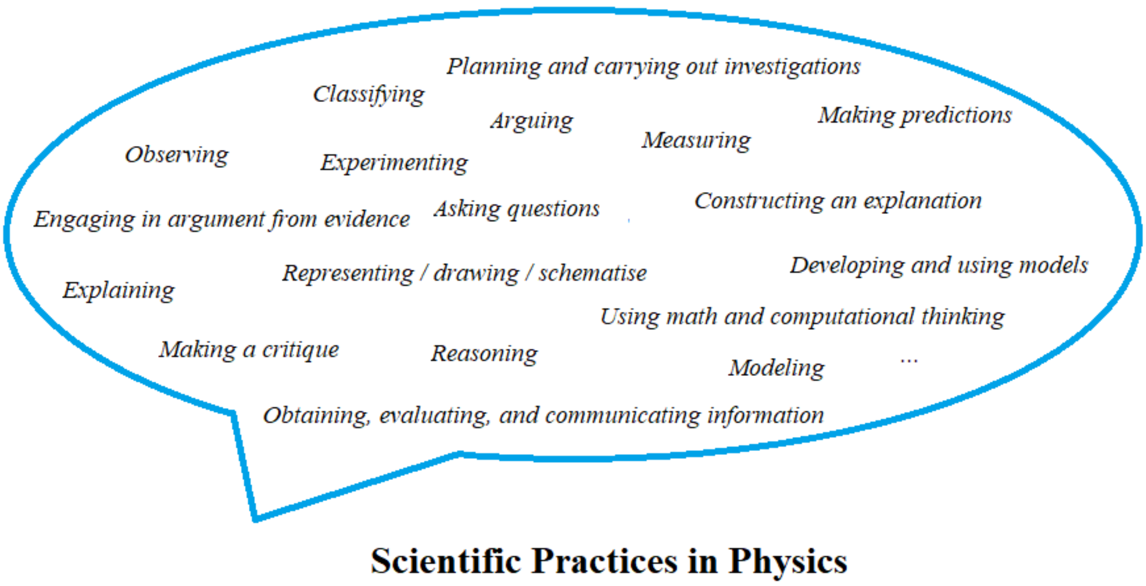
For getting a better idea of what we mean by scientific practices, in addition to the point of view of Erduran and Dagher, I have consulted another contribution. It is about the Eight Scientific Practices proposed by the National Research Council (2012). This organisation is the working arm of the United States National Academies, which produces reports that shape policies, inform public opinion, and advance the pursuit of science, engineering, and medicine.

The Eight Scientific Practices are:

1. Asking questions (for science) and defining problems (for engineering).
2. Developing and using models.
3. Planning and carrying out investigations.
4. Analyzing and interpreting data.
5. Using math and computational thinking.
6. Constructing an explanation (for science) and designing a solution (for engineering).
7. Engaging in argument from evidence.
8. Obtaining, evaluating, and communicating information.

Many of these practices were already included in the Benzene Ring Heuristic, like "analysing data" or "constructing explanations"; others are added or better explained, like "using math and computational thinking". By converging these two contributions into a single corpus, I drew up a list of some practices of physics (Figure 3.1), which have served as a guideline during the analysis, of which I will describe in detail in the following paragraphs.

Figure 3.1. Scientific practices in physics.



3.3. Tool to collect analysis data

To collect the data, useful for the analysis about scientific practices in physics lessons of Italian high school, I have interviewed five physics teachers. For this purpose, an interview protocol was developed by me, following the interview protocol refinement (IPR) framework proposed by

Castillo-Montoya (2016). This framework illustrates how an interview protocol can be developed for qualitative research, ensuring reliability and good quality of data obtained from interviews.

For developing the protocol interview, it is necessary to follow four phases: (1) ensuring interview questions align with research questions; (2) constructing an inquiry-based conversation; (3) receiving feedback on interview protocols; (4) piloting the interview protocol.

The first phases led me to select interview questions that are not equivalent to the research questions, but that aims to collect information, to answer to research questions. I have built a list of questions useful to collect information about: the career and experience of the teachers interviewed; the actual situations of scientific practices teaching, in particular what and how teachers drive the scientific practices teaching in physics lessons and the support given by the official didactics tool or textbooks; the benefits achieved by the student, thanks to the teaching of physics, which includes the practices of science.

The second phases allowed me to choose the best language for developing a formal dialogue with the teacher, without creating a sense of detachment and distance; and avoiding misunderstandings and confusion, when the question would be asked. Moreover, in this phase a precise structure is given to the protocol: to help teacher to feel involved in an increasingly personal dialogue about their experience, the structure of interview protocol starts with short and specific questions, while at the end it foresees more general and open questions.

The last two phases (receiving feedback and piloting the interview protocol) has been done during a lesson of “Advanced Professional and Research Skills in physical Sciences” course, where I presented and discussed the protocol created by me with the classmates and teachers.

In Table 3.2, it is shown the final interview protocol that I developed and used to collect the data for the analysis about scientific practices.

Table 3.2. Interview protocol.

Informative questions	What did you graduate in?
	What subjects do you teach, or have you taught in your professional experience?
	How many years have you been teaching?
	In what kind of schools did you teach and at what levels?
Specific questions	What textbook have you adopted in recent years? What use do you make of the textbook in your teaching?
	As I said before, my study focuses on the so-called epistemic practices, such as modeling, argumentation and scientific explanation, that is, practices that highlight the (epistemological) dimensions of physics as scientific discipline. Do you include activities or lessons on these practices in your teaching? (In the event that the teacher replies that he treats them either explicitly or implicitly) What do you think is the usefulness or value of these practices?
	What is the reaction of your students to themes / activities / practices of this type?

	Do you believe that the textbook can be of help in developing skills related to these epistemic practices (like modeling, argumentation, explanation)?
General questions	As part of my research, I am also trying to understand if the study of physics can help the students to achieve citizenship skills. Do you believe that physics has a cultural value in this sense? And, specifically, which citizenship skills can be developed also and above all through the study of physics?
	Thinking about the student as a future citizen and the skills he will need, what physics image should be conveyed through textbooks and how?

3.3.1. Sample

The teachers of physics, I have interviewed, are five teachers with different backgrounds and teaching experiences, who work in high schools in Emilia Romagna, and have a particular attention to the epistemological aspects of the discipline.

Below, I will illustrate the profiles of the teachers, highlighting their experience level (early-career, if the teacher teach for less than ten years; mid-career, if the teacher teach for less than 25 years; end-career, if the teacher teach for more than 25 years or is retired), their degree, and the typologies of school in which they work or have worked:

1. Early-career teacher graduated in physics, and who teaches at “Liceo Scientifico” high school.
2. Mid-career teacher graduated in Mathematic and having a PhD in Mathematics. He/she teaches at “Liceo Scientifico” and taught at “Liceo Artistico” and “Liceo Classico” high schools.
3. End-career teacher graduated in physics, who taught at “liceo Scientifico” high school and “Istituto tecnico” high school.
4. Mid-career teacher graduated in Environmental Engineering, who teach in “Istituto tecnico” high school.
5. Mid-career teacher graduated in Aerospace Engineering and having a PhD in Engineering. He/she teach at “Istituto tecnico” high school and had taught at “Istituto professionale” high schools.

3.4. Methods for analysing interviews

After interviewing the five teachers, each interview, recorded, was transcribed into a Word file. The shortest recording lasted 30 minutes, while the longest lasted 59 minutes. The data collected and the topics covered in these interviews were very rich and differentiated.

Therefore, to analyse the data, I decided to organise and visualize the data of each interview, in two steps:

1. In the first step, I have done a thematic analysis. The collected data of each interview have been organized by topic. For this scope, I build a table, in which each rows represented a topic touched during the interview like, for example, "*the activities that the teacher proposes regarding argumentation"; "the importance that the teacher gives to these activities"; "students' problems"* (both in learning physics in general, and specifically in understanding and practicing epistemic practices)*; "what textbooks should offer to help physics practices teaching"; "the value that physics teaching has for student's culture".* A final row was used to collect the most common words said by each teacher.

   The table looks like Table 3.3. There are eighteen lines (the topics) and five columns, one per teacher. Obviously not all the teachers talked about all the eighteen topics, so some cells remained empty. The creation of this table was long but allowed me to organize the data, having a first overview on all the interviews. Still, it allowed me to discover commonalities and differences between the teachers. For example, all teachers denounced the lack of epistemic and cognitive aspects of physics in the textbooks, but every teacher proposed different potentialities of this tool (*they have multimedia content; they offer exercises and problems in real situations; they should give insights*…) or suggestions for improvement (*textbooks should offer parts of original texts; they propose videos on physics experiments*).

Table 3.3. Table to organise the interview data (thematic analysis).

	Topics	**T 1**	**T 2**	**T 3**	**T 4**	**T 5**
1	Teaching style					
2	Activity on modeling					
3	Students' problems on modeling					
4	Activity on arguing					
5	Students' problems on arguing					
6	Activity on explaining					
7	Students' problems on explaining					
8	Importnace of these activities					
9	Students' problems in general					
10	Students' reactions to these activities					
11	How it is structured the textbook					
12	The teacher uses it for…					
13	Do not uses it for…					
14	How the textbook should be/ what it should contains					
15	Textbook issues					

16	What idea of physics to teach					
17	The value of physics for citizens					
18	Most common words					

2. After schematizing the information, these were used to build a map (one per interview), that shows the main nodes, touched in the interview by the teacher. The map has been built to provide a structural overview of teachers' interviews. The nodes are not only the themes, that the teacher particularly stressed, but also activities that the teacher proposes for physics practices teaching and personal ways to manage the lesson. This map has been a second step for "cleaning" the interview information, letting the personal contribution of each teacher to emerge, so not all the themes of thematic analysis were included into the maps, but only the more significant or original ones. Each map has been useful to visualise the contributions of the teacher in only one page, allowing me to notice if the diverse parts of the interview were connected and converging into a particular direction, and to compare two or more interviews in a more agile way.
   Each map is built positioning in the centre the name of the teacher. Around the name are placed the "nodes" that most represent that teacher. That nodes, that are denoted with a number, refers to the activities about physics practices proposed by the teacher. Each activity is contextualised in a specific physics subject and address a specific need of students. In the map, when some nodes or statements are strongly related to others, arrows or outlines have been added to specify it. Thanks to the thematic analysis, I noticed that in some interviews there was aspects, that recurred in several themes: it was an aspect that the teacher particularly care about. I decided to dedicate a special node to these aspects and to insert them in the maps because I wanted to highlight these distinctive features of the teachers. In the map of the third teacher, there is the node "*Creation of a scientific thought*", because that teacher stressed the importance of building scientific thought and the special importance for her to this practice. Also, in the map of the fourth teacher, there is a special node called "*Teaching the physics practices through a reasoned lesson",* to highlight his personal way of teaching; and in the map of the fifth teacher, there is a node called "*Visualise to understand*", to highlight the importance of the teacher give to practices of visualising and representing

3.5. Results

In the previous chapter, we saw that scientific practices are present into the physics guidelines, even if the task of concretizing and contextualizing the teaching of this important aspect of the nature of physics is often delegated to the teachers. The analysis of interviews focused on (a) understanding what really is done by teachers to include scientific practices into the physics lessons; (b) which benefits, both related to the discipline understanding and cultural skills achieved, through teaching of physics practices.

In this paragraph, the results of interviews analysis are shown, both describing the maps and the most significant sentences, said by the teachers. From Figure 3.2. to Figure 3.6, the five maps, that show the data collected through the interviews to teachers, are provided.

3.5.1. Teacher 1

The teacher speaks mostly of physics practice of modelling. She tells that students have problems when, in kinematics, they should recognise the physics situation described into the exercises text. They have problems in understanding that different contexts can refer to the same physical situation and can be solved using the same model. The teacher proposes to rewrite the exercise text, substituting to the words of the real situation with names referred to the model (e.g. ball with material point), or, at the contrary, to invent a new exercise text, referring to a real context, starting from the models.

Another problem of students, related to modelling, is, for the teacher, the understanding of what means *modelling* in physics. When the teacher teaches the geometric optic, he/she drives a discussion about the details of the real-life situation that should be considered by a physicist (and which not) for building the model, that describes that situation.

The teacher says that modelling can promote significant reflections when two models (of the same object) are compared. For example, in the case of physical optics, two models of light are compared: the limits of validity and the prediction and explanatory powers of the two models are discussed. The teacher explains why these reflections are significant: *"The discourse about the limits of validity of the model is important because some students, once they know the model or the formula, tend to use it unconditionally, without wondering if that particular situation is suitable for applying that formula or that model. It is necessary to clarify certain things that, otherwise, would be always taken for granted".*

These activities, also, help the students to be aware of what is behind a simple formula or behind a physics theory, and that physics has its own structure and way to build knowledge, differently from other disciplines. Moreover, the students have the opportunity to position themselves and ask themselves if their way of reasoning is similar or very far from that of physics.

Other three interesting contributions given by the teacher are about textbooks, students' reactions and citizenship skills: she says that actually the textbook is "a collection of examples", because it reports many exercises, already done, to train students to use the formulas. She says:

“reading the textbook does not mean to clearly understand the modelling or the argumentation: often in the textbook there is no explicit argumentation or explanation of what a model; there are no underlying assumptions and limits of validity”. Under the careful supervision of the teacher, the textbook can be used, and often contains useful multimedia activities. About students’ reactions to modelling activities, they are “amazed”, because they did not believe that making physics means to take such care of languages or reasoning, and “it’s fun” when they understand the “game rules” of physics and became involved. The teacher explains why physics and physics practices help students to achieve skills, and why they are useful for their future as citizens: *“I believe that physics can train reasoning, and form the ability to observe a situation and identify which are the important elements; it teaches to argue in a logical way, to make hypotheses; to make a critical analysis of the information that one reads and listens… Then, it teaches the ability to see the structure behind reasoning and see if it holds; what are the hypotheses on which it is based; what are the consequences; try to identify connections, analogies and see a structure in complexity; to be able to interpret complex phenomena, identifying models and asking if this model is found in other situations. All this, in my opinion, is fundamental, regardless of whether one is studying a physical phenomenon, a sociological, or whatever, because, basically, we all live in complexity.”*

Among the words most used by the teachers appear: exercise, modeling, formulas, constructing, reasoning, structure, ability.

3.5.2. Teacher 2

The teacher is focused on practices of reasoning and modeling, remarking many times the fundamental importance of the logic structure of physics reasoning. About textbooks, she utilises almost only the part dedicated to the exercises, because in the theorical part of book, in which concepts, laws and theories are explained, , she sees the lack of logic connections that should lead a student to understand the reasoning or how a knowledge has been built. The teacher says that in textbooks knowledge is given at the beginning, instead it would be achieved as final result of a solid reasoning.

She says that reasoning and modeling work always together. She does not teach the practice of modeling as a separate topic, but when the class deals with a model in a concrete situation. Together with students, the starting hypothesis, the validity of the model and its features are discussed. The students appreciate these moments: when they discuss and confront with each other, they can express themselves freely without immediately fear of making a mistake; unlike when they solve an exercise, where they feel there is a right-wrong dichotomy.

The teacher believes that logical reasoning and modeling help the students to understand what the scientific methods is. That is more important than teaching the single content, because in their future the students need to know how to build or recognise a logical reasoning "when they approach information in every day's life, they need to have 'thinking tools'".

"The book sometimes does not help the student in the process of building the model: it does not clarify what I have to study and which aspects to focus on; how to select the important elements and exclude the things that don't matter. All this fatigue in the textbooks is completely purified and hidden. The text is useful when it explains the logical passages of a reasoning that was the basis for the construction of a concept". According to the teacher, this fatigue, this building of a logical structure, is what makes physics beautiful. Also, the students rediscover the interest and passion for physics when they understand the logical structure of the discipline.

Among the words most used by the teachers appear: textbook, modeling, logic, understanding, idea, theory, fatigue.

Figure 3.2. Maps representing the data collected during the interview of the first teacher.

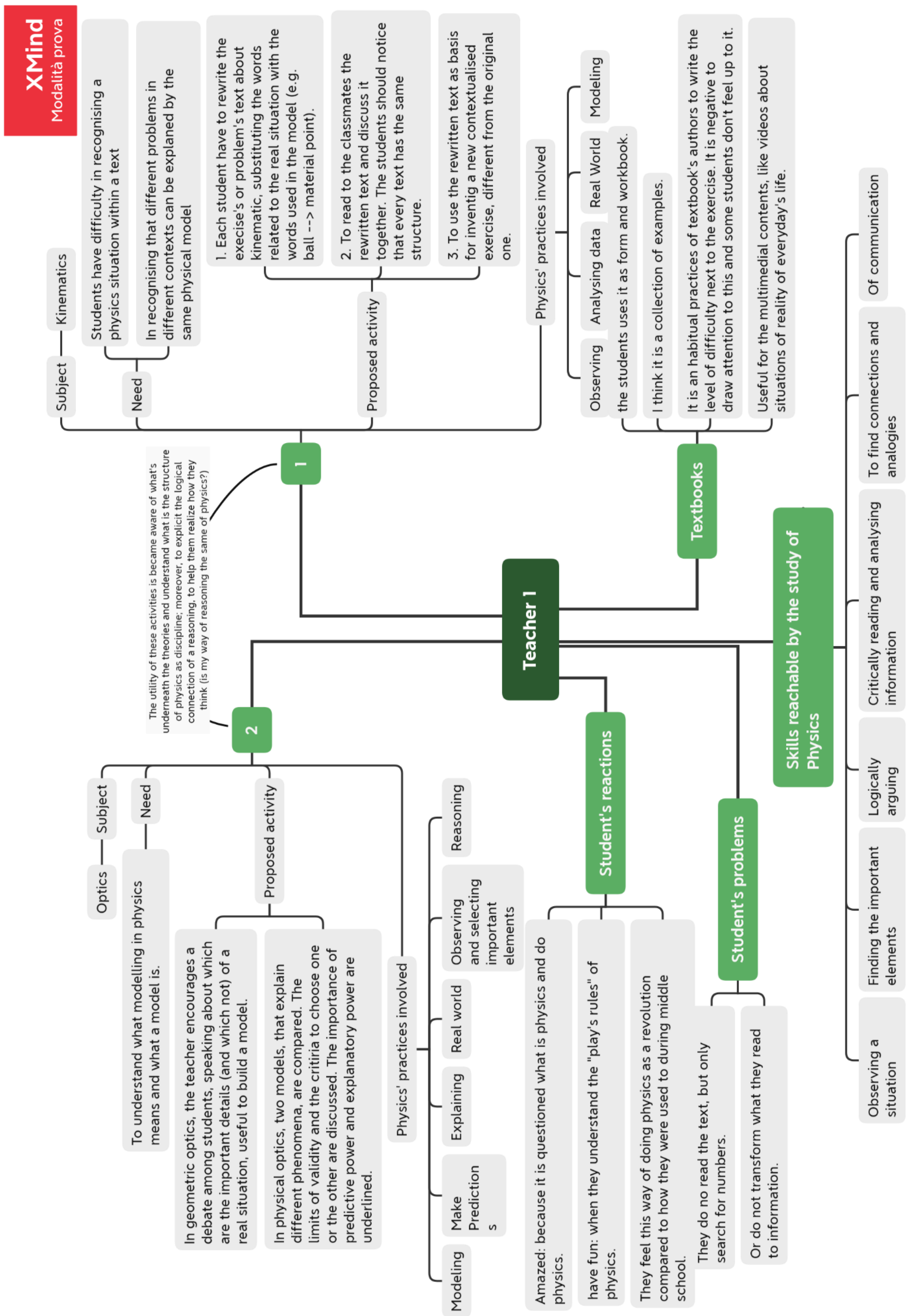
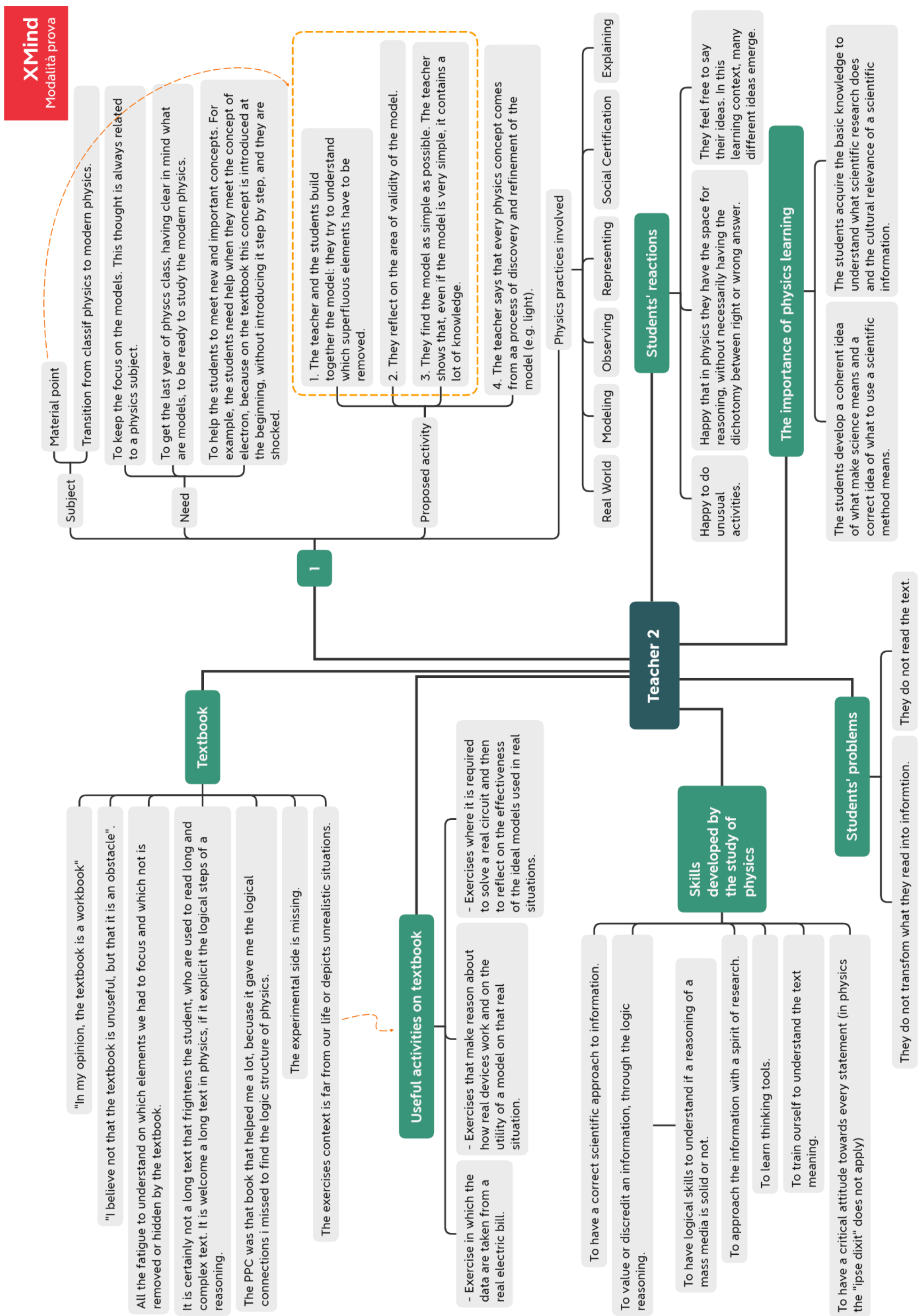


Figure 3.3. Maps representing the data collected during the interview of the second teacher.



3.5.3. Teacher 3

The teacher is focused on epistemic and cognitive practices of physics. She believes that practices in physics allow the students to understand how the knowledge is developed. These practices should be trained: *"if I do not remember a formula or a law, I can surf the internet and find it. But if I am not able to follow a reasoning, a demonstration, the construction of a thought... these skills can be acquired through scientific thinking".*

The teacher proposes debates and collective reasoning, together with students, trying to understand the logical structure and the hypothesis behind a model or a theory; moreover, she/he promote reflections about the validity of knowledge (e.g. what happens when we have a boundary problem, which can be addressed with two different theories?). As the teacher says: "*it is important to clarify that it is not so true that what is consolidated and scientifically recognized, is then all strictly coherent, but it is influenced by a philosophical substrate and influenced by the ideas and knowledge of the historical period in which this theory was born and grew up*".

The teacher says that all these reflections are picked up by the students, who realize their crucial relevance to understand the discipline.

An activity that the teacher promotes to push students to reason about physics concepts like time and space and their implications, consists in writing a story that tells about a word in which velocity of light is near to our typical velocities. The students must describe how would be this world. Another activity the teacher uses is, given an exercise and the solutions, to motivate the results using only a written reasoning and then using the theory or model they prefer. Through these activities, students are trained to observing, modeling, reasoning, making predictions, and explaining, without having a unique way to follow. They are given the opportunity to find their place in physics.

The teacher says that the students appreciate those moments in which they can think and debate together, without any judgment; those moments in which "thought is cultivated"; when they can approach the problem in their personal ways; when they understand which structure stays behind concepts.

The teacher says that experimental and laboratory activities are also important moments for bringing out the methodological and conceptual peculiarities of physics. A cultural value of experiments and making physics in general, is the encounter with (and normalization of) errors and frustration: *"Because when you solve a problem, those who are truly learning and are not applying mere techniques have to deal with the error, with the frustration that arises when you are* *unable to do something, when you do not find the way or are in difficulty. That moment must be the training ground for managing error and frustration"*.

Among the words most used by the teachers appear: thought, error, thinking, concept, problem, construction, value, people.

3.5.4. Teacher 4

The teacher is mainly focused on practices of experimenting and reasoning. The teacher develops a "reasoned" lesson: the new concepts are built together, are not given by the teacher; the reasoning starts from the common-sense knowledge of students; when possible, the historical development of concepts is explained; when possible, the teacher prefers to start from the experimental observation of the phenomenon. The role of the teacher is support students in critical reasoning and observing of phenomena.

The teacher believes that the laboratory activities are important to understand that errors are fundamental for learning, and that physics do not follow predetermined steps or deals with "nice" situations and linear results. He proposes situations in which students have to ask themselves how to organise the instrumental equipment to obtain the best measure. The error is used to understand if all is going well or to project a better setting. Most part of the students at technical schools prefer touch with hands the situations, instead solving exercises using the mathematical approach. The experimentation allows the students to appreciate and understand many aspects of the discipline.

The teacher thinks that the textbook he adopted has often the lack of argumentation aspects and were too much concise. A more step by step development of knowledge, giving space to the epistemological aspects of physics, would be better.

The cultural value of teaching physics and physics practices is summarised in these words of the teacher: *"students tend, because they were born and raised in a society of this type, to seek simple answers, to seek the fastest answers, to seek "trivialization", because it is the simplest way. In front of a complex situation it is necessary to take time for deepening, verifying, listening to the opinion of others, waiting for the response of a test. This is part of the scientific method. To allow them to understand that, in a society as complex as ours, there are no simple answers, it is a great achievement of citizenship"*. Also, he said: *"Once, my teacher said: 'Culture is what remains when we no longer remember anything'. In this sense, I think that physics gives us so much, even though one day we won't remember anything anymore"*.

Among the words most used by the teachers appear: problem, understanding, building, difficulty, reasoning, modeling, laboratory, method, reality.

Figure 3.4. Maps representing the data collected during the interview of the third teacher.

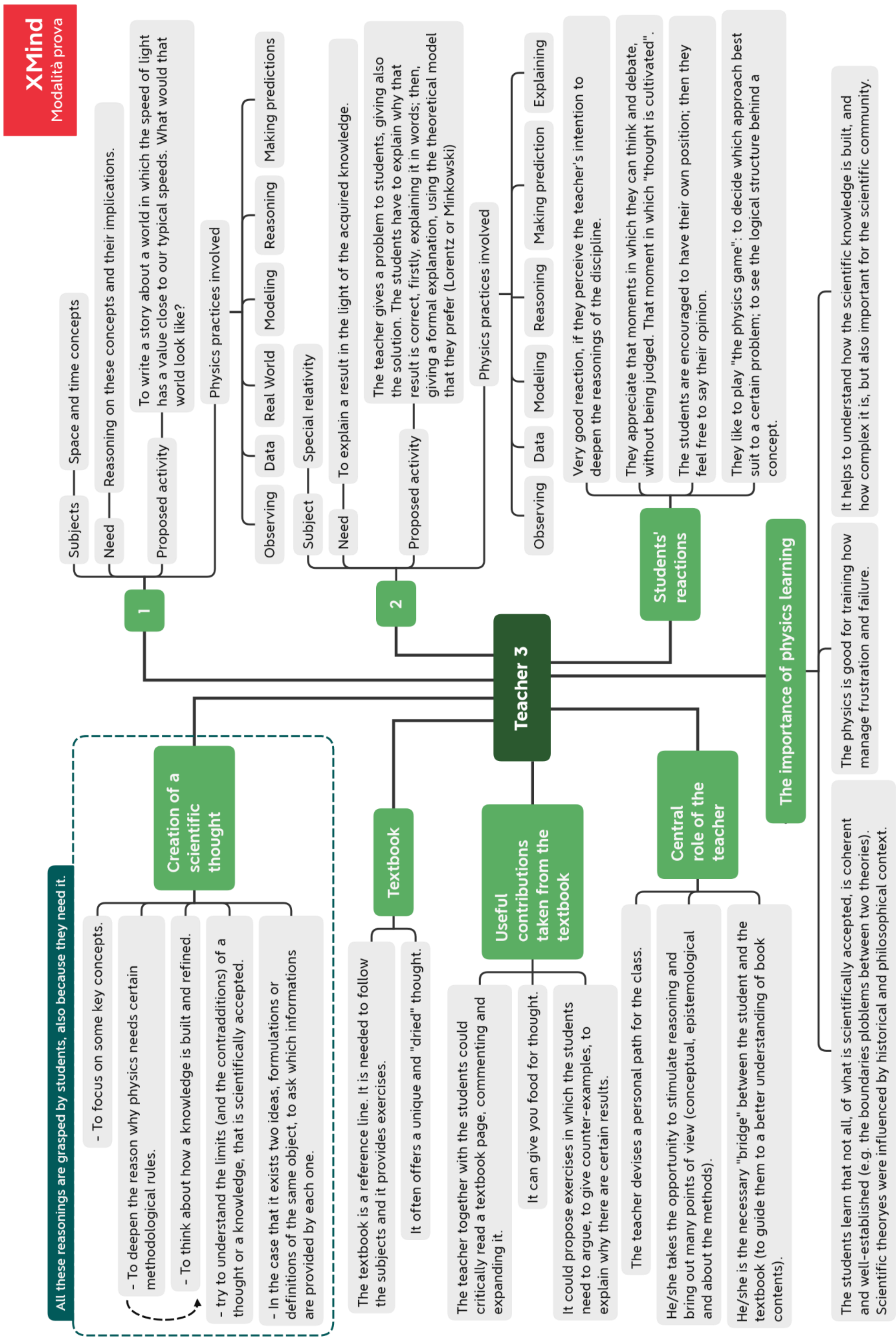
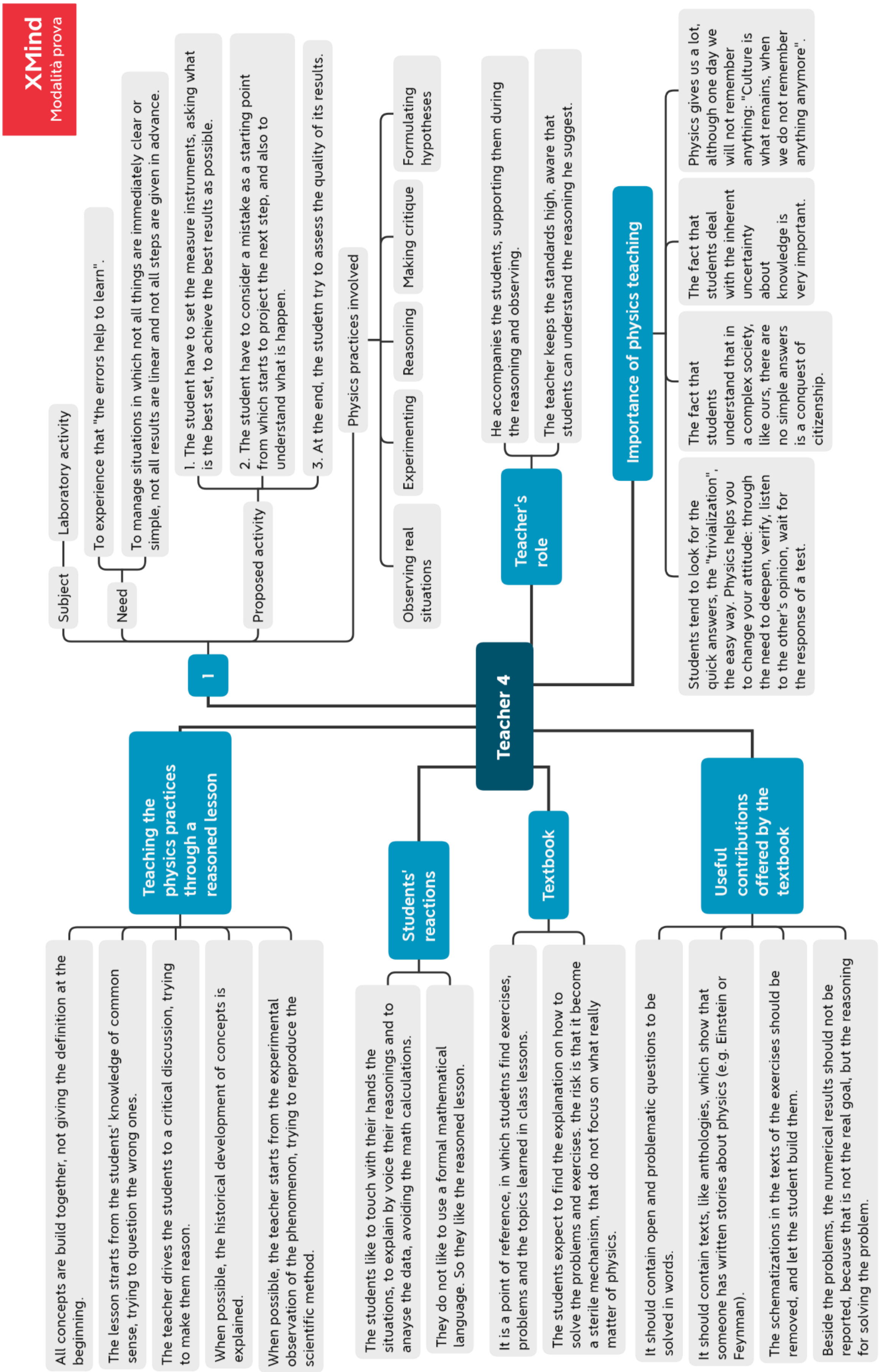


Figure 3.5. Maps representing the data collected during the interview of the fourth teacher.



3.5.1. Teacher 5

The teacher is focused on practices like modelling and representing using draws. For example, to teach the concept of density she proposed an activity in which students should observe different objects, then represent it, drawing how it could be structured in the inside. After, the model is built together, comparing the different drawings and experiences of students. At the end, the model is formalised, and its validity is discussed and explained. Another example of activity, that contains practices of observing, drawing and modelling, concerns the gravitational field. After observing how a ball rests on a suspended sheet, they must try to model that situation, drawing it.

During these activities there is a great exchange of ideas. The students participate a lot, trying to invent their own representation, and have a lot of curiosity during the activity. She said, speaking about a typical situation in class during the activity: *"I tell them that they must create something; that there is neither good nor wrong. After a first moment of disorientation, they create something, and then they are amazed, because they did not believe to know so many things"*.

Many students understand that the model is a form of knowledge that allows you to study things completely different, without the need to study in a mnemonic way.

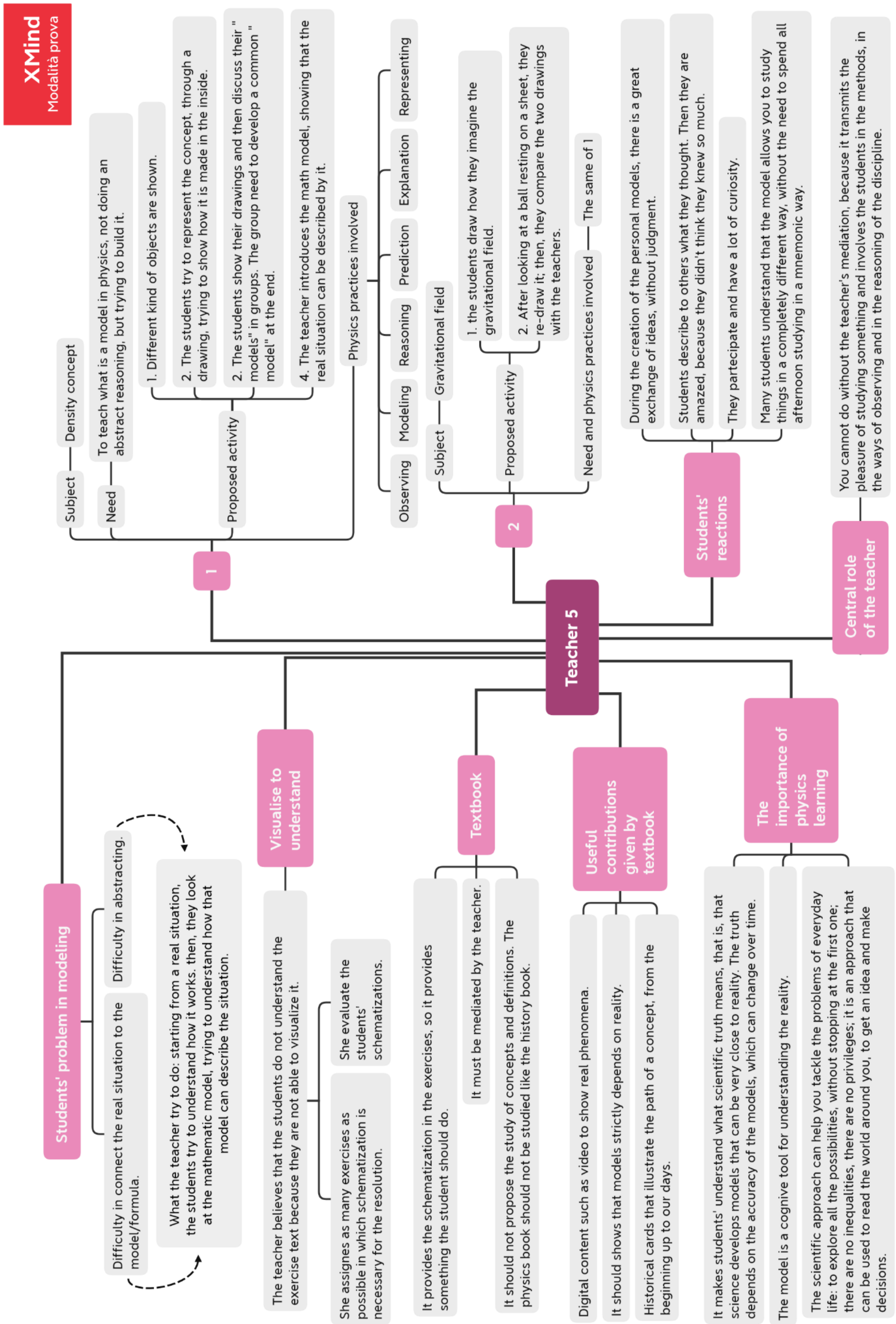
The teacher believes that observing is useful to understand: all the problems assigned to students, require that the situation is schematized. Only through the schematization, it is possible to understand the important elements for the resolution.

The teacher believes that the teaching of modelling allows students to understand what scientific truth means, in the sense that science elaborates models that can be very close to reality; and the truth depends on accuracy of models, which can change over time: *"Often, in the first lesson I do, the first thing that I say is that Science has limits, and I tell the students that the truth depends on the precision of the models, that are precarious knowledge, and that can change over the time"*.

In general, speaking about the importance of teaching science, she said that the scientific approach is very important for the students as citizens, because it teach them to search for all the possibilities, and do not stop at the first thing that you see; and to explore many alternatives. That is a good practice also in everyday life, when you must take a choice or when you approach a person, avoiding stopping at the first judgement.

Among the words most spoken by the teachers appear: modeling, drawing, video, reality, explaining, difficulty, citizen.

Figure 3.6. Maps representing the data collected during the interview of the fifth teacher.



3.6. Discussion of the results

Our aim was to understand what role scientific practices was given by physics teachers in their teaching in high schools. Through interviews, the voice of the teachers allowed us to recognise many roles that epistemic and cognitive practices in physics like modeling, argumentation, reasoning, representation, observation and experimentation can play.

In the teaching of physics, it emerged that the practices are fundamental to achieve the primary objective of the physics class: a coherent and rich understanding of physics as scientific discipline. Through epistemic practices like modeling, and cognitive practices like reasoning, the teacher accompanies the students into the disciplines, exploring and discovering it from inside. It is through modeling, exploring the possibilities, discussing limits of validity, experimenting, making hypotheses, making errors, that the students meet and understand the physics.

Another important contribution attached by the teachers to physics practices is that the students can experience genuine involvement in the physics lesson: there is the possibility and the pleasure to experience the epistemic dimensions of discipline, that is what gives meaning to knowledge. The authentic nature of physics is discovered when the students actively participate in developing knowledge, when they search to position themselves within the discipline, asking if they agree with the way of facing a problem of physics, and when they authentically contribute to the lesson. The students are said to be enriched a lot if they have the time to reason, to build a thought, to defend an idea. For these reasons, it is extremely important that the teacher suspends the judgment towards the students in these stages of learning.

All the teachers highlighted that often textbooks do not have epistemic elements of physics, the logical steps and the fatigue that physicians have done in developing knowledge. These are instead elements the students need to authentically engage with physics and deeply understand it.

Moreover, the practices of physics can have enormous cultural values: the student and the teacher recognize a connection and similarity between scientific skills and social skills, such as the ability to compare ideas, to analyse complex contexts and to evaluate which option or information is more reliable and evidence-based. In a so complex and fast-changing society like our, in which people need to take fast decisions or evaluate situations of which they do not know so much, the skills achieved with the study of physics practices, became very important to be critical citizens.

There are also emotional values related to the study of physics practices: the laboratory activities bring the students close to concepts like measure error and uncertainty, training them to have a positive relationship with error and failure, seen as opportunities to improve a condition or discover something new. Also, the discussing and reasoning about the limits of validity of a model and the inconsistencies between two theories are opportunities to show to students that science and physics are not perfect, but human, as us.

Physics practices show to students how much it is important to give time to find the best solutions to complex problems. As the teachers said, also we live in a complex society, and physics helps us to remember that we shouldn’t search for trivial solutions, only because they are the fastest, but we should take time to find the best one. And this is demanding, yes.

Conclusion

In this thesis, I presented studies I have done about a specific paradigm, used in science education, that is the Family Resemblance Approach applied to Nature of Science, and reconceptualised for science education as RFN. I have adopted this framework in two types of analysis. In the first one, I used the RFN to identify the elements of NOS in the physics guidelines for the "Liceo Scientifico" high school in Italy (the official syllabus). In the second type of analysis, the RFN was used as a reference to dialogue with physics teachers and analyse what and how elements of Nature of Science are taught in high school physics teaching.

In developing these studies, I had the need and the chance to deal with several methods and methodological aspects used in science education research.

I developed an analytic grid to analyse the physics guidelines and treat them carefully as data source. During the development of that tool, I had to face the problem of creating a reliable tool, usable to perform multiple independent analysis, ensuring to get comparable results. When I translated the guidelines from Italian to English, I had to face the problem to produce a reliable translation, that does not distort the meaning of the original text. For this reason, I used a translation tool to do the bulk of the translation, and then I double checked the translation, reading and correcting it by myself and by asking a colleague, proficient both in Italian and English languages and expert in physics, to do the same.

During the analysis of the guidelines, I have used the method elaborated by Miles and Huberman (1994), to calculate the percentage agreement between the two independent analyses, and I have carried out a reconciliation phase, to make sure that the data obtained were as more shared and objective as possible.

I utilized the Epistemic Network Analysis, a type of analysis useful for visualizing connections between fixed elements. I studied how the analysis works on the tutorial written by Shaffer et al. (2016). Then, I wondered what the meaning of the obtained results was. In my case, the ENA analysis was fundamental to point out all the possible connections between the NOS categories, that subsequently I re-analysed one by one, to discriminate which were significant.

I developed an interview protocol, following the interview protocol refinement framework proposed by Castillo-Montoya (2016), to interview physics teachers. This protocol had to satisfy multiple values. The questions had to be non-ambiguous and therefore guarantee the reproducibility of the interview data. Also, the questions had to be useful to collect information, to answer my research questions. I had to develop both specific and general questions, to let the interviewed teachers to say their own point of view.

I had to analyse very differentiated data: the data extracted from the guidelines were few and specific. I needed to represent and analyse them, to highlight their meaning and their structure. The data collected in the interviews were on the contrary very rich and complex, because the interviews lasted up to an hour, and fostered deep discussions on many aspects of teaching. In this case I had to face the problem of data reduction. I needed to "clean" the interviews from superfluous information, to show both the common aspects of teachers' interviews, and the idiosyncratic aspects. For this scope, first, I made a thematic analysis, reorganizing the data according to the topics covered by the teachers into a table. With this process, I identified the common traits that emerged from the various interviews. Subsequently, I built five maps, that shown the personal and characterizing contributions of the various teachers. Although there is a common ministerial program, the aspects of NOS are often implicit, and must be grasped by the teachers, thanks to their experience, professionalism, sensitivity, and culture. There are some explicit elements of NOS in the guidelines, but they are very few and, in any case, the teachers are free to choose how to deal with them and contextualize them. For this reason, it was extremely important to bring out the voice of each teacher, to highlight what room is there for didactic choices on the approaches that can be adopted.

Through these methodological instruments, I obtained many results. From the analysis of the physics guidelines, I found a consistent presence of NOS elements, that relate to cognitive-epistemic aspects of science, in contrast to a scarce presence of NOS categories related to social-institutional system of science. In the general part of physics guidelines, the NOS element more present is "scientific practices", followed by "aims and values", "scientific knowledge" and "methods and methodological rules", that highlight the general intention of the guidelines authors to promote epistemic and cognitive aspects of physics. In the specific part of physics guidelines, the NOS categories of "knowledge" became predominant on the others. This highlights a big focus that however led to pay less attention and care to the other NOS elements. Still, I noticed that in the guidelines it is frequently delegated to the teachers the creation of the conditions for learning the experimental, methodological aspects and values of the discipline.

Through the ENA analysis on the physics guidelines, I found a discrete presence of connections between the cognitive and epistemic NOS categories. The connections between social-institutional NOS categories were almost absent, even though they would be very significant to students understanding of the research processes in physics and its social dynamics. I found a result, warrying for students' education, that is the total absence of connections with the social-institutional NOS categories in the first two years of physics course.

Through the interviews with teachers, about scientific practices teaching, the importance of this NOS category for physics understanding emerged very clearly: teachers retain that the students do need to understand how to "play" the physics game, that is how to model, to observe a real situation, to critically manage with information and scientific instrumentation. It emerged that scientific practices train student in reasoning and in scientific thinking. The analyses pointed out that teachers think that explicitly addressing physics practices is fundamental to authentically engage students with physics, discovering, also, its limits. The analysis also pointed out that teachers retain that physics practices do help students achieve cultural skills, like the ability to give credit, or not, to an argument that they might hear from the mass media; and achieve emotional skills, like the ability to handle error and failure.

I believe this experience has been very positive for my professional career and for my personal life. I enjoyed to enter the debate on the Nature of Science and realise, more and more, that questions, like "what is science?" or "what I should teach about physics?", are anything but trivial; but that exists researchers that concretely tried to answer it. The analysis of physics guidelines makes me realize how complex is to develop it, but also how much important is to have a common line, clearer and more explicit, from which every teachers can start to develop their own contributions to students.

I loved to meet five passionate teachers and discover so many issues and also so many good aspects of physics teaching. These teachers gave me a lot of food for thought, they transmitted to me how valuable the teacher job is and how much passion is necessary to do it.

This experience allowed me to encounter very different research environments. I believe that the work I did with Professor Levrini, and the support I received from the class of "Advanced Skills", was very rich, full of useful advice and exchanges of interesting ideas. I improved a lot my skills, to approach physics education research.

I had also the opportunity to experience an international and prestigious research environment, such as that of the University of Oxford. I had the honour to collaborate with the research group in science education, led by Professor Erduran, one of the most competent and active researchers in the European science education research scene, current president of ESERA. I am very proud that the work, I have done with prof. Erduran and Dr. Cullinane, is considered interesting by them to the point of dedicating additional time, in addition to *Erasmus Plus* period, to write a research paper together.

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Appendix

Appendix A: Tables used for physics guidelines analysis

		Cognitive-epistemic system				Social and institutional context
	GENERAL GUIDELINE AND SKILLS FOR 5-YEARS PHYSICS COURSE AT "LICEO SCIENTIFICO" HIGH SCHOOL	Aims and values	Scientific practices	Methods and methodological rules	Scientific knowledge	
G.1	At the end of the high school programme, the student will understand the fundamental concepts of physics, the laws and theories that address them, becoming aware of the cognitive value of the discipline and the link between the development of physical knowledge and the historical and philosophical context in which it evolved.					
G.2	In particular the student will have acquired the following skills: observing and identifying phenomena;					
G.3	formulating explanatory hypothesis through the use of models, analogies and laws;					
G.4	formalizing a physical problem and applying the mathematical and disciplinary tools which are relevant for its solution;					
G.5	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 and of the reliability of the measurement process, the model construction and/or validation;					
G.6	understanding and evaluating the scientific and technological choices that affect the society in which the student lives.					
G.7	The freedom, competence and sensitivity of the teacher - who will ponder each time the most suitable educational path for each class - will play a fundamental role in finding connections with other courses (in particular with the mathematics, science, history and philosophy ones) and in promoting collaborations between the school and universities, research institutions, science museums and the world of work, especially for the benefits of the students of the last two years.					
G.8[3]	In particular, for the high school of applied sciences, the central role of laboratory is stressed, both as activities where presentations are conducted at the teacher's desk and as experiences of discovery and verification of physical laws. These activities make the student understand the inductive nature of the laws and gain a concrete perception of the connection between experimental evidence and theoretical models.					
total						

[3] G.8 subsection relates to applied sciences-oriented curriculum only.

		Cognitive-epistemic system				Social and institutional context
	SPECIFIC GUIDELINE AND SKILLS FIRST BIENNIUM	Aims and values	Scientific practices	Methods and methodological rules	Scientific knowledge	
1.1	In the first two-year period, the basis of the language of classical physics are constructed (scalar and vector physical quantities and units of measurement), and the student will get used to simplify and model real situations, to solve problems and to be critically aware of his/her own work.					
1.2	At the same time, laboratory experiments will allow to clearly define the inquiry field of the discipline and the student will be able to explore phenomena (develop skills related to measurement) and to describe them with appropriate language (uncertainties, significant figures, graphs). The experimental activity will accompany the student throughout the first two years, leading him/her to an increasingly aware knowledge of the discipline, also through the writing of reports that critically re-elaborate each performed experiment.					
1.3	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.					
1.4	The study of thermal phenomena will define, from a macroscopic point of view, the physical quantities of temperature and exchanged heat by introducing the concept of thermal equilibrium and by addressing the state transitions.					
1.5	The study of mechanics will examine problems related to the equilibrium of bodies and fluids; the motions will be firstly addressed from a kinematic point of view, arriving at the dynamics with a preliminary exposition of Newton's laws, with particular attention to the second one.					
1.6	From the analysis of mechanical phenomena, the student will begin to familiarize with the concepts of work and energy, to arrive at a first discussion of the law of conservation of total mechanical energy.					
1.7	The recommended topics will be developed by the teacher in a manner and in an order to be decide according to the conceptual tools and the mathematical knowledge that the students already have or which are developing in the parallel course of Mathematics (as specified in the related Indications). The student will thus be able to experience, in an elementary but rigorous form, the inquiry method typical of physics, in its experimental, theoretical and linguistic aspects.					
total						

		Cognitive-epistemic system				Social and institutional context
	SPECIFIC GUIDELINE AND SKILLS SECOND BIENNIUM	Aims and values	Scientific practices	Methods and methodological rules	Scientific knowledge	
2.1	In the second two-year period, the educational programme will give greater importance to the theoretical framework (the laws of physics) and to the formal synthesis (mathematical tools and models), with the aim of formulating and solving more demanding problems, also drawn from daily experience, underlining the quantitative and predictive nature of physical laws.					
2.2	In addition, the experimental activity will allow the student to discuss and construct concepts, design and conduct observations and measures, compare experiments and theories.					
2.3	The laws of motion will be analysed in more depth, and inertial and non-inertial reference systems and Galilei's principle of relativity will be discussed.					
2.4	The detailed study of the principle of conservation of mechanical energy, also applied to the motion of fluids, and the comparison with other principles of conservation will allow the student to re-read the mechanical phenomena using different quantities and to extend their study to systems of bodies. With the study of gravitation, from Kepler's laws to Newtonian synthesis, the student will analyse in detail the debate on cosmological systems in the XVI-XVII centuries, also in relation to history and philosophy.					
2.5	The study of thermal phenomena will be concluded with the laws of gases, familiarizing with the conceptual simplification of the ideal gas and its kinetic theory; the student will thus be able to see how the Newtonian paradigm is able to connect the microscopic world to the macroscopic one. The study of the principles of thermodynamics will allow the student to generalize the law of conservation of energy and to understand the intrinsic limits of the transformations between forms of energy, also in their technological implications, in quantitative and mathematically formalized terms.					
2.6	The study of wave phenomena will begin with mechanical waves, introducing their characteristic quantities and mathematical formalization; phenomena related to their propagation will be examined, with particular attention to superposition, interference and diffraction. In this context, the student will familiarize with sound (as an example of a particularly significant mechanical wave) and will complete the study of light with the analysis of phenomena that highlight its wave nature.					
2.7	The study of electrical and magnetic phenomena will allow the student to critically examine the concept of interaction at distance, already encountered with the law of universal gravitation, and to overcome it by introducing interactions mediated by the electric field - which will be described also in terms of energy and potential - and by the magnetic field.					
total						

		Cognitive-epistemic system				Social and institutional context
	SPECIFIC GUIDELINE AND SKILLS FIFTH YEAR	Aims and values	Scientific practices	Methods and methodological rules	Scientific knowledge	
3.1	The student will complete the study of electromagnetism with magnetic induction and its applications and will arrive to the synthesis provided by Maxwell's equations; for this study, the conceptual aspects will be emphasized.					
3.2	The student will also face the study of electromagnetic waves, their production and propagation, their effects and their applications in the various frequency bands.					
3.3	The educational programme will include the knowledge developed in the XXth century relating to microcosm and macrocosm, combining the problems that have historically led to new concepts of space and time, mass and energy. The teacher will have to pay attention to use a mathematical formalism which is accessible to students, always highlighting the foundational concepts.					
3.4	The study of Einstein's special relativity theory will lead the student to deal with the simultaneity of events, the dilation of time and the contraction of lengths; having addressed the mass-energy equivalence will allow the student to develop an energetic interpretation of nuclear phenomena (radioactivity, fission, fusion).					
3.5	The establishment of the model of the quantum of light can be introduced through the study of thermal radiation and Planck's hypothesis (even only in a qualitative way), and will be developed on the one hand with the study of the photoelectric effect and its interpretation by Einstein, and on the other with the discussion of theories and experimental results that highlight the existence of discrete energy levels in the atom. The experimental evidence of the wave nature of matter, postulated by De Broglie, and the uncertainty principle could conclude the programme significantly.					
3.6	The experimental dimension can be further deepened with activities to be carried out not only in the school didactic laboratory, but also in universities and research institutes laboratories, also within orientation projects.					
3.7	In this context, the student will be able to study topics of interest in more details, approaching the most recent discoveries of physics (for example in the field of astrophysics and cosmology, or in the field of particle physics) or analysing the relationships between science and technology (for example the issue of nuclear energy, to acquire the scientific terms useful for critically approaching the current debate, or semiconductors, to understand the current technologies also in relation to consequences on the problem of energy resources, or micro- and nanotechnologies for the development of new materials).					
total						