Chapter 2
Family Resemblance Approach to Characterizing Science

The chapter draws on the Family Resemblance Approach (FRA) to inform characterisations of nature of science in science education. The components of the FRA are described and a rationale is provided for its relevance in science education. The FRA can provide a fresh new perspective on how science can be conceptualized in general and how such conceptualisation can be useful for teaching and learning of science in particular. The FRA is described and extended being mindful to have sufficient context and content for it to be of use for science education purposes. Izrik and Nola's (2014) depiction of FRA, which describes components of science in terms of categories subsumed under epistemic, cognitive and social systems is used. However, these authors framework does not provide an extensive discussion. Indeed, the description of their categories is rather brief. The aim of the chapter is to build on the FRA itself and explore its potential for use in science education. In applying the FRA to science education, Irzik and Nola's philosophical model is developed into a functional framework for instructional and learning purposes throughout the rest of this book. In particular, the authors' linguistic and textual account is transformed into a visual representation that highlights the need for a dynamic and interactive tool representing science in a holistic account. The transformed FRA informs the content and structure of the chapters.

2.1 Introduction

As discussed in Chap. 1, there are multiple ways in which nature of science has been defined, and various arguments advanced to support different formulations. We take the position that nature of science in its broader sense encapsulates a range of practices, methodologies, aims and values, and social norms that have to be

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acknowledged when teaching science. Restricting nature of science in the context of school science to a limited set of ideas about the nature of scientific knowledge unduly results in limited attention to other core factors that influence the formation and validation of scientific claims. For example, not understanding the way in which cultures of science are constituted and how these cultures contribute to the development of scientific knowledge will result in a rather narrow understanding of science as a human endeavor.

Irzik and Nola (2011a, 2014) attempt to address the unity of science without sacrificing its diversity by pursuing a Family Resemblance Approach. Basing their notion of family resemblance on Wittgenstein's work, they present their scheme as an alternative to the consensus view, arguing that it is "more comprehensive and systematic" (Irzik & Nola, 2014, p. 1000). The advantage of using the FRA to characterize a field of science is that it allows a set of broad categories to address a diverse set of features that are common to all the sciences. This is particularly useful in science, whereby all subdisciplines share common characteristics but none of these characteristics can define science or demarcate it from other disciplines. For instance, Irzik and Nola (2014) present the example of observation (i.e. human or artificial through the use of detecting devices) and argue that even though observing is common to all the sciences, the very act of observing is not exclusive to science and therefore does not necessarily grant family membership. The same applies to other practices such as inferring and data collecting, which are shared by science fields but their use is not necessarily limited to them.

The family resemblance model of nature of science conceptualizes science in terms of a cognitive-epistemic and a social-institutional system. The analytical distinctions Irzik and Nola make are meant to "achieve conceptual clarity, [and] not [serve] as a categorical separation that divides one [dimension] from the other. In practice, the two constantly interact with each other in myriad ways" (Irzik & Nola, 2014, p. 1003). This is a critical distinction to uphold in this chapter as well as the rest of the book. Science as a cognitive-epistemic system encompasses processes of inquiry, aims and values, methods and methodological rules, and scientific knowledge, while science as a social-institutional system encompasses professional activities, scientific ethos, social certification and dissemination of scientific knowledge, and social values.

Within the cognitive-epistemic system, Irzik and Nola discuss four categories[1] described briefly as follows. The processes of inquiry considered in this scheme refer to types of activities that are rather familiar to science educators. They include activities like "posing questions (problems), making observations, collecting and classifying data,

[1] In the rest of the book we will use the term 'category' to denote the key components of science as a cognitive-epistemic and social-institutional system (see Table 2.1). In emphasizing the pedagogical applications and implications of the FRA framework, we will refer to 'epistemic', 'cognitive' and "social-institutional" aspects. At times, for the sake of brevity, we will collapse "social-institutional" aspects into 'social' or "social context".

designing experiments, formulating hypotheses, constructing theories and models, comparing alternative theories and models" (Irzik & Nola, 2014, p. 1007).

Aims and values refer to a set of aims in the sense that the products of scientific activity are desired to fulfill them. Aims and values include some obvious ones "such as prediction, explanation, consistency, simplicity and fruitfulness" (Irzik & Nola, 2014, p. 1007). Aims also include viability, testability, and empirical adequacy that function both as aims and values, and at times they function as shared criteria that play a significant role in theory choice.

Methods and methodological rules refer to the variety of systematic approaches and the rules that scientists use to ensure that they yield reliable knowledge. Included in these methods are different strategies such as inductive, deductive and abductive reasoning. Equally important to the methods are the set of methodological rules that guide their use. Examples of methodological rules are such statements as: "other things being equal choose the theory that is more explanatory," "use controlled experiments in testing casual hypotheses," and "in conducting experiments on human subjects always use blinded procedures" (Irzik & Nola, 2014, p. 1009). Scientific knowledge refers to the 'end-products' of scientific activity that culminate in "laws, theories, models as well as collection of observational reports and experimental data" (Irzik & Nola, 2014, p. 1010). Reference to end products is focused on the epistemic and cognitive aspects of these entities, how they become established, and what differentiates them from one another.

Within the conception of science as a social-institutional system, Irzik and Nola (2014) offer four categories that include professional activities, social and ethical norms, community aspects of science work, and the relationships of science with technology and society. Irzik and Nola are quick to admit that these categories are not exhaustive and that this may not be necessarily the best way to describe the social aspects of science. The shift in their original conception from sole focus on cognitive aspects of science (Irzik & Nola, 2011a) to adding one category of social context (Irzik & Nola, 2011b) to including four categories embedded under science as a social-institutional system creates more balance between the cognitive-epistemic and the social-institutional factors. This balance reflects the complex nature of science. It is also relevant to the broader goals of science education, as will be demonstrated throughout the book.

A brief description of the four categories under the social-institutional dimension follows. Professional activities refer to activities that scientists perform in order to communicate their research, such as attending professional meetings to present their findings, writing manuscripts for publications and developing grant proposals to obtain funding. Scientific ethos refers to the set of norms scientists follow in their own work and their interactions with one another. These include Mertonian norms (i.e. universalism, organized skepticism, disinterestedness, and communalism) as well as other ethical norms elaborated by Resnik (2007). The latter include things such as honesty and respect for research subjects and the environment. The social certification and dissemination of scientific knowledge refers to the peer review process, which tends to work as a "*social quality control* over and above the *epistemic control* mechanisms that include testing, evidential relations, and methodological consideration" (Irzik & Nola, 2014, p. 1014). The social values of science refer values such as "freedom, respect for the environment, and social utility broadly understood to refer to improving people's health and quality of life as well as to contributing to economic development" (Irzik & Nola, 2014, p. 1014) (Table 2.1).

These categories are not mutually exclusive entities but are complementary in the sense that they target different dimensions of the scientific enterprise. They are identified in separate categories to allow a more detailed analysis. Given the complexity of the scientific enterprise, it is helpful to disentangle some of its components, especially those that constitute commonalities across different domains. Irzik and Nola (2011a, 2011b; 2014) note that even though the processes, aims and values, methods and methodological rules, knowledge claims and the four aspects of the social institutional system may differ across science domains, there is enough resemblance along these categories within and across domains that make them recognizable as scientific.

Irzik and Nola (2014) describe the Family Resemblance Approach itself as follows:

> Consider a set of four characteristics {A, B, C, D}. Then one could imagine four 440 individual items which share any 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 any three properties chosen from the original set of characteristics. This example of a polythetic model of family resemblances can be generalised as follows. Take 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. In what follows we will employ this polythetic version of family resemblance (in a slightly modified form) in developing our conception of science. (Irzik & Nola, 2014, p. 1011)

They then proceed to argue that there are characteristics common to all sciences and some that are rather specific in emphases to particular sciences. For example, sciences share such practices as collecting data and making inferences. Other features of activities of science such as experimentation, however, might be differentiated. Irzik and Nola (2014) give the example of astronomy and earth sciences. These domains cannot possibly rely on experiments as celestial bodies cannot be manipulated. Likewise, earthquakes cannot be manipulated in the experimental sense. The authors situate the Family Resemblance Approach further by providing a disciplinary approach:

> Let us represent data collection, inference making, experimentation, prediction, hypothetico-deductive testing and blinded randomised trials as D, I, E, P, H and T, respectively. Then we can summarise the situation for the disciplines we have considered as follows:
>
> Astronomy = {D,I,P,H};
> Particle physics = {D,I,E,P,H};
> Earthquakescience = {D,I,P′,H};
> Medicine = {D,I,P″,E,T}, where P′and P″ indicate differences in predictive power as indicated.

Table 2.1 Family resemblance approach (Irzik & Nola, 2014, p. 1009)

Science							
Science as cognitive-epistemic system				Science as a social-institutional[a] system			
1	2	3	4	5	6	7	8
Processes of inquiry	Aims and values	Methods and methodological rules	Scientific knowledge	Professional activities	Scientific ethos	Social certification and dissemination of scientific knowledge	Social values

[a]The Table in Irzik and Nola (2014, p. 1009) does not reference to 'Institutional'. However the corresponding aspect discussed in their paper is "Social-Institutional System" as a section heading. Therefore we include the word 'institutional' in our reproduction of the Table

Thus, none of the four disciplines has all the six characteristics, though they share some of 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.

Overall, The FRA provides an account where the domain-general and domain-specific aspects of science can be articulated. Illustrating the interplay between family resemblance features and how they get expressed in domain-specific contexts across science disciplines are addressed throughout the book.

2.2 Justifying the Family Resemblance Approach

One of the appealing aspects of the FRA is its ability to consolidate the epistemic, cognitive and social aspects of science in a wholesome, flexible, descriptive but non-prescriptive way. FRA provides focus zones that support the discussion of critical elements about science which can potentially be fruitful for science educators as well as teachers and students. It creates a much-needed space for conversation and dialog about science in a comprehensive way. It is this invitation to dialog that has intrigued us and provided us a foundational place to develop and expand what Irzik and Nola (2011a, 2011b, 2014) originally argued. As philosophers, they have presented a compelling justification for their framework. Their account is broad enough to accommodate further development and expansion. As science educators, we recognize in their framework a comprehensive organizational scheme that enables us to unpack the complex ideas that we judge worthy of expansion and application in science education.

Another advantage to the FRA is that it is an expansive framework that incorporates many components of existing nature of science frameworks. To elaborate this idea, two existing frameworks are considered, the consensus view and the features of science view, the latter intended to be a revisionary account of nature of science in science education. The components of three frameworks are aligned in Table 2.2 to illustrate how ideas from the consensus view and the FOS view relate to the FRA. The notation with the question mark (?) refers to instances where a comparable concept is either not explicitly present or could not be identified. Only a small set of ideas that represent philosophical positions such as constructivism, realism and feminism under the FOS approach are not directly addressed in the FRA because, as explained earlier, the FRA takes a neutral stance towards these positions. One could argue that these philosophical stances are constituted within the articulation of the eight categories that Irzik and Nola (2014) discuss. However, their work on FRA does not explicitly address these positions. The FRA framework appears to subsume all the individual components of the consensus and FOS frameworks.

Of note in this comparison is the difference in orientation afforded by the FRA in comparison to the consensus approach to teaching NOS. The FRA addresses a higher level of organization involving a *class of ideas* approximating common characteristics. In contrast, the consensus view addresses *individual ideas* about science. For example, the FRA refers to scientific knowledge as a key cognitive epistemic category about science. In contrast the NOS consensus view distinguishes between scientific theories and laws. The former (i.e. scientific knowledge) is a class of ideas whereas the latter is an individual idea within that class. This is a fundamental difference between these two approaches. In our view, the higher level of organization in the FRA is precisely its strength as it lends itself to flexible exploration of those aspects about science that are most relevant to target science content. Ultimately, the purpose of the FRA as applied in educational settings is neither to teach students individual ideas nor to teach them specific philosophical doctrines about science but rather to promote holistic and contextualized understanding of science.

As Table 2.2 illustrates, FRA seems to capture a meta-level characterization of the key categories related to science in a broad sense. In other words, the FRA is more inclusive of various aspects in its depiction of science. It is the holistic, inclusive, diverse and comprehensive and meta-level conceptualization of FRA that has been appealing to us as science educators. Having awareness of a wider range of NOS issues does not necessarily mean that the curriculum, the teachers and the students will now be burdened with having to cover them all at once. The framework mainly invites selecting those issues about science that are of immediate relevance to the big ideas that are already under study. It alerts us to the missing components about the nature of science in science education such that we could make intelligent decisions about which aspect to prioritize when and for what purpose. Furthermore, having a more diverse representation of science has potentially more appeal to a wider range of students. For example, students who may not necessarily be drawn to the epistemic dimensions of science, may now find more motivation and interest in the social-institutional aspects of science. Hence, FRA approach potentially can be more inviting to learners. Arguably, some of the categories represented in the FRA may not conventionally be familiar to science teachers. We envisage this conversation to be the beginning of a new territory of professional development as well as research in science education. As illustrated in subsequent chapters, particularly in Chap. 8, there are also potentially fruitful spaces for policy makers in considering the often-neglected aspects of nature of science in the science curriculum.

Apart from a comprehensive set of categories about the cognitive-epistemic and social-institutional aspects of science, “family resemblance” enables the articulation of science through a set of comparisons between the different branches of science, thus allowing the consideration of domain-general as well as domain-specific set of characteristics of science. The “family resemblance” theme provides a much needed coherence to how we can envisage science from a more holistic perspective. In other words, while individual components from the particular eight categories might have been captured in other depictions of nature of science, these individual components can remain rather disconnected without an overarching and cohesive theoretical framework. The consequence of such lack of coherence between the different categories of science can potentially lead to restricted understanding about science.

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

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

Often in school science, it is indeed observed that students are introduced to rather discrete set of features of the nature of science without a meta-level understanding of how these discrete features relate to one other. The “family resemblance” approach has the potential to inform and generate more pedagogically, cognitively, and epistemically sound models of nature of science for science education.

2.3 Extending the Family Resemblance Approach

As mentioned earlier, one of the advantages of the FRA is that it lends itself to further development and to incorporation of related ideas. In order to keep the terminology clear, there are specific instances where we have intentionally modified or extended components in the FRA framework. More details on this are provided in individual chapters. However, a brief reference to two modifications is useful at this stage.

Irzik and Nola (2011a, 2011b) initially used the term ‘activities’ to refer to ideas involving processes used in scientific inquiry. In later work (Irzik & Nola, 2014), they referred to them as “scientific processes”. For reasons detailed in Chap. 4, the terms ‘activities’ and ‘processes’ are substituted with ‘practices’. Using “scientific practices” in the context of the FRA establishes a healthy distance from the over-use and narrow meanings often associated with science process skills in science education, and the generally all-encompassing sense implied by scientific activities. More importantly, it aligns the range of activities involved in this category with those included in the contemporary science education literature (Duschl, Schweingruber, & Shouse, 2007; NRC, 2012).

The original FRA framework (Irzik & Nola, 2011a) included four main categories focused on the cognitive aspects of science. In a revised account, Irzik and Nola (2011b) introduced institutional and social norms as a fifth component that encompassed Merton’s norms, social values and research ethics. In a more recent account, the authors (Irzik & Nola, 2014) elaborated on the fifth component by transforming it into a social-institutional dimension. This dimension includes four clearly defined categories: professional activities, scientific ethos, social certification and dissemination, and social values. The authors explicitly give examples of potential categories that can be included but they chose to limit their discussion to four that are non-controversial in nature. Chapter 7 provides a rationale for why additional categories that might be considered by some as controversial (e.g. the economic and colonial aspects of science) should be included under the social-institutional dimension and provides examples for how these categories might be taught in the science classroom.

A final organizational distinction is that the sequence of discussion in Irzik and Nola’s (2014) version of FRA is as illustrated in Table 2.1. In other words, they begin the articulation of the FRA with reference to processes of inquiry followed by aims and values, and so on. We deemed it more appropriate to start the articulation and extension of the framework by focusing on the aims and values of science. Focusing on the goals, the targets and embedded values in science should set the pretext for how the subsequent aspects such as practices, methods, knowledge and social-institutional contexts are framed. Although this is an organizational distinction, it also has implications for how the application of FRA in science education can be framed such that its various components make sense particularly from a developmental and cognitive point of view. It would be inconceivable for science students to comprehend and appreciate the value of scientific knowledge without a foundational sense of what science is trying to achieve and how. Likewise the sequence of practices, methods and knowledge also is intended to facilitate the understanding of science in a coherent way.

2.4 The FRA as a Holistic Model

How do the components of science as a cognitive-epistemic system relate to those of science as a social-institutional system? This relationship is considered in terms of the graphic representation or model presented in Fig. 2.1 which includes a set of categories that we have added to the Irzik and Nola's (2014) version. The idea can be characterized in the following way. Science as a cognitive-epistemic system occupies a space divided into four quadrants that accommodate its four categories as discussed earlier. This circle floats within a larger concentric one also divided into four quadrants, pertaining to the four components of science as a social-institutional system. The boundaries between the two circles (or spaces) and their individual compartments are porous, allowing fluid movement across. In reality, these

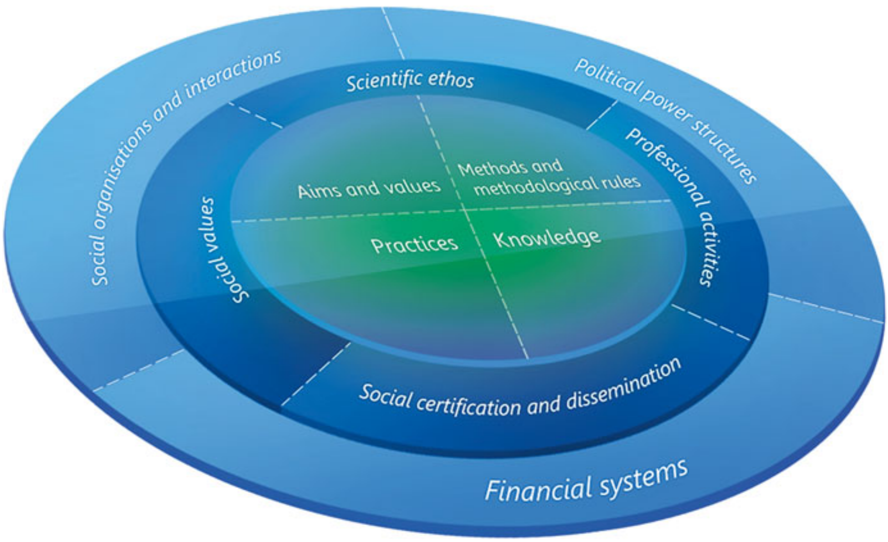

Fig. 2.1 FRA wheel: science as a cognitive-epistemic and social-institutional system

components are not compartmentalized but flow naturally in all directions. The purpose of this representation is to provide a visual tool for showing, at-a-glance, how all the components of the cognitive-epistemic and social-institutional systems interact with one another, enhancing or influencing scientific activity. The significance of visualization for facilitating teaching and learning of science is well established (e.g. Gilbert, 2005).

The transformation of the Irzik and Nola's (2014) FRA conceptualization from a textual format to a concentric circle model enhances the depiction of science as a holistic, dynamic, interactive and comprehensive system subject to various influences. Although our representation has to create divisions so as to illustrate the various components, the notion that all of the cognitive, epistemic and social-institutional components co-exist as a whole provides a departure from representing science relative to particular discrete set of ideas. In our view, the image provides a distinctive contribution to research on nature of science (NOS) by offering an interactive, visual and holistic account. These aspects of the representation (and indeed the representation itself) are deemed as improvements to the consensus NOS and FOS frameworks discussed earlier given that their depictions of NOS tend to focus on specific propositions that do not capture adequately the desired degree of breadth and interconnectedness of ideas about science in educational contexts.

In adapting the FRA for science education purposes, we recognized that the social-institutional aspects are limited in Irzik and Nola's (2014) framework. For instance, the political aspects of science were not explicitly acknowledged. Hence we have extended this dimension of FRA to include three additional categories that are discussed in more detail in Chap. 7. We refer to these extra categories as "social organizations and interactions", "political power structures" and "financial systems". The original FRA model has thus been modified to include the additional social-institutional categories as re-represented in Fig. 2.1 by adding the outer-most circle. The reworked framework provides a comprehensive representation of different aspects that characterize the scientific enterprise. Weaving a broader set of social-institutional aspects into the cognitive-epistemic aspects of science is likely to serve a wider range of learners especially those who may not be drawn to the cognitive aspects that dominate school science. The framework serves the agenda of promoting a more balanced and comprehensive account of NOS for all science learners.

Having reviewed the key features of the FRA framework, its adaptation and extension, next we present an example that illustrates how the FRA can be situated in a concrete context. The discovery of the structure of DNA illustrates the broad categories that underlie the FRA framework. James Watson and Francis Crick published the double helix model of DNA in Nature in 1953 (Olby, 1994). Their account was based on the X-ray diffraction image generated by Rosalind Franklin and Raymond Gosling a year earlier as well as information from Erwin Chargaff on the pairing of bases in DNA. Maurice Wilkins and his colleagues had also published results based on X-ray patterns of DNA which provided evidence for the double helix model proposed by Watson and Crick. Watson, Crick and Wilkins were acknowledged jointly for the discovery of the structure of DNA following the death

Table 2.3 Application of FRA categories to the context of DNA discovery

FRA	DNA example
Aims and values	Although the base, sugar and phosphate unit within the DNA was known prior to the modeling carried out by Watson and Crick, the correct structure of DNA was not known. Their quest in establishing the structure of DNA relied on the use of such existing data objectively and accurately to generate a model for the structure. Hence the values exercised included objectivity and accuracy
Practices	In their 1953 paper in Nature, Watson and Crick provide an illustration of the model of DNA as a drawing. Hence they engaged in providing representations of the model that they built. They also included the original X-ray diffraction image generated by Franklin on which their observations were based. The scientific practices of representation and observation were thus used
Methodology	The methods that Watson and Crick used Franklin's X-ray diffraction data which relied on non-manipulative observation. Hence the methodology involved particular techniques such as X-ray crystallography and observations
Knowledge	The main contribution in this episode of science is that a model of the structure of DNA as a double helix was generated. This model became part of scientific knowledge on DNA and contributed to a wide range of scientific disciplines including chemistry, molecular biology and biochemistry
Social and institutional context	This episode illustrates some of the gender and power relations that can exist between scientists. There is widespread acknowledgment in the literature and also by Crick himself, for instance, that Franklin was subjected to sexism, and that there was institutional sexism at King's College London where Franklin worked (Sayre, 2000/1975, p. 97). The DNA case also illustrates that science is both a cooperative and a competitive enterprise. Without Franklin's X-rays, Watson and Crick would not be able to discover the correct structure of DNA. This is the cooperative aspect. However there was also competition within and across teams of researchers

of Franklin. The extent to which Franklin's contribution has been acknowledged has emerged as a contentious issue. In particular, there is widespread recognition that Franklin experienced sexism (Sayre, 2000/1975) (Table 2.3).

The DNA example illustrates how the FRA framework can be applied in science education. Clearly the argument for the inclusion of these various features of science is not new. Numerous science education researchers have already made this argument as is pointed out in the following sections. However, what is novel about this approach is that when covered together, in a collective and inclusive manner, nature of science is presented to learners in a more authentic and coherent fashion. When students confront this and other examples positioned in a similar way (where now comparative aspects across examples can be pursued as well), the "family resemblance" element can also be drawn in. For instance, the precise nature of observation in terms of it being a "scientific practice" in the DNA example can be contrasted with another instance, say, an example from astronomy to draw out the similarities and differences between observation practices in different branches of science.

Identifying the components of science as a cognitive-epistemic and social-institutional system is a beginning step in the design of curricula and lesson materials. We are cognizant of the fact that this example only serves to identify particular topics through which lesson contexts can be generated. The pedagogical strategies that accompany the realization of the FRA framework need to also be considered. Some instructional issues are discussed in Chap. 8 after the components of the system are covered across the book in more detail. There are implications for teacher education as well, in terms of familiarizing science teachers with the content of topics that are likely to be taught in a decontextualised fashion. Teacher educators will need to extend the framework for professional development purposes to support teachers' incorporation of FRA components in their science lessons.

2.5 The Relationship of FRA to Research Traditions and Policy in Science Education

It is worthwhile at this stage to discuss how FRA relates to existing research traditions within science education as well as to curriculum policy. The intention is to be illustrative in order to provide a rationale for the relevance of FRA in science education research and policy. In the rest of the book, each component of FRA is covered in more detail in each chapter and more specific links will be made to research and policy.

The FRA framework is related to a wide range of research in science education, which may have historically developed in an unrelated and disparate fashion. The holistic and inclusive nature of the FRA framework opens up opportunities to incorporate for instance, history of science, as well as cognitive models for scientific reasoning, into the design and evaluation of curriculum units. Those opportunities are enhanced by a strong research-base in science education. For example, there is considerable research on students' ideas about the nature of science. Some studies focus on articulating developmental differences in children's understanding of the nature of science (Driver, Leach, Millar, & Scott, 1996; Hammer & Elby, 2000) while other studies document some of the difficulties and successes students encounter with understanding the NOS consensus view (e.g. Lederman, 2007). There is also a plethora of assessment instruments that provide good starting points for developing new formative and summative assessments using findings learned from the application of the VNOSS (Abd-El-Khalick & Lederman, 2000; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) and the KNOWS (Allchin, 2012). The literature on socio-scientific issues can inform how investigations of socio-scientific issues contribute to an improved understanding of NOS (Eastwood et al., 2012; Sadler, 2011; Zeidler, Walker, Ackett, & Simmons, 2002). Case studies on NOS implementation from different countries, as well as insights from theoretical studies, can provide useful ideas for developing innovative NOS resources (Grandy & Duschl, 2008; Matthews, 2014). A variety of linguistic and discourse tools can facilitate the implementation of scientific practices (Erduran, 2007; Kelly, 2011; Sandoval, 2005). Curriculum studies can enhance re-conceptualizing the integration of integrating an FRA approach to NOS teaching (Donnelly, 2001; Rudolph, 2000; Schwab, 1964). Finally, studies on the critical use of history of science (Allchin, 2013; Erduran, 2001; Matthews, 1994, 2012; Milne, 1998) can be used to enrich instruction on nature of science.

In addition to its compatibility with these research traditions, the FRA is also compatible with policy frameworks such as past (AAAS, 1989; NRC, 1996) and recent science education reforms in the USA (NRC, 2012). Even though the *Framework for K-12 Science Education* [*FKSE*] (NRC, 2012) does not designate a specific chapter to discuss the nature of science as the *Science for All Americans* [*SFAA*] document did, the spirit of NOS is integrated throughout its content. The *FKSE* calls for a triadic emphasis on three dimensions: scientific and engineering practices, disciplinary core ideas, and crosscutting concepts. These dimensions are expected to be taught in an interrelated and coherent way leading to the realization of a normative goal in which "students should develop an understanding of the enterprise of science as a whole—the wondering, investigating, questioning, data collecting and analyzing" (NGSS Lead States, 2013, p. 1). This meta-level of understanding aligns well with the categories of the FRA. In Table 2.4, we list a few examples of how categories of the FRA correspond to the vision promoted in the *Framework for K-12 Science Education* (2012) and to expectations about students' understanding of the nature of science based on Appendix H in the *Next Generation Science Standards* (NGSS Lead States, 2013). These examples are not the only ones that can be found in the documents, but they represent well the ideas contained therein. Even though the reform vision and ensuing standards may not be directly relevant to readers outside the United States, we believe that a similar analytical process can be undertaken with curriculum standards of other countries.

Although there seems to be some overlap of the FRA categories with existing statements in policy recommendations, the particular ways in which policy statements articulate, or fail to articulate, aspects of the FRA becomes an issue. For instance, take the reference to the "Social and Institutional Context" category from Table 2.4. The statements are rather broad and do not necessarily indicate which aspects of the social or the institutional dimensions of science are to be emphasized and how. It is also not clear where such dimensions need to be included in science lessons. If the emphasis is on cognitive-epistemic and social-institutional contexts becomes an add on, the goal of presenting science to learners in a holistic fashion is lost. What results is that the various dimensions of science are emphasized and prioritized selectively and persistently while others become peripheral and 'cosmetic' to serve a very generic and broad goal. The outcome of such an approach is that students learn a distorted, decontextualized and incoherent view of the nature of science.

Table 2.4 Alignment of FRA categories with recent reform documents in the USA

FRA	Framework for K-12 Science Education (NRC, 2012)	Next Generation Science Standards (NGSS Lead States, 2013)
Aims and values	"Epistemic knowledge is knowledge of the constructs and values that are intrinsic to science." (NRC, 2012, p. 79)	"Science Addresses Questions About the Natural and Material World."
		"Scientific information is based on empirical evidence." (p. 4)
Practices	"…important practices, such as modeling, developing explanations, and engaging in critique and evaluation (argumentation)… Engaging in argumentation from evidence understanding of the reasons and empirical evidence for that explanation, demonstrating the idea that science is a body of knowledge rooted in evidence. (p. 44)	"Students must have the opportunity to stand back and reflect on how the practices contribute to the accumulation of scientific knowledge…. Through this kind of reflection they can come to understand the importance of each practice and develop a nuanced appreciation of the nature of science." (p. 7)
Methodology	"Practicing scientists employ a broad spectrum of methods…" (NRC, 2012, p. 44)	"Scientific Investigations Use a Variety of Methods." (p. 4)
Knowledge	"Students need to understand what is meant, for example, by an observation, a hypothesis, a model, a theory, or a claim and be able to distinguish among them." (NRC, 2012, p. 79)	"Science is a Way of Knowing."
		"Scientific Knowledge is Open to Revision in Light of New Evidence."
		"Scientific Models, Laws, Mechanisms, and Theories Explain Natural Phenomena." (p. 4)
Social and institutional context	"Seeing science as a set of practices shows that theory development, reasoning, and testing are components of a larger ensemble of activities that includes networks of participants and institutions…." (p. 43)	"Science is a Human Endeavor" (p. 4)

2.6 Potential Challenges in Applying the FRA in Science Education

The brief description of the FRA categories in this chapter may perplex the reader on different levels. For starters, the approach seems complex. It groups NOS ideas in unfamiliar ways; seems to place high cognitive demands on students; and may seem challenging to teachers. This section addresses some of these potential concerns.

The apparent complexity of the FRA is precisely its core strength. It is complex at first sight, yet it is simple in terms of helping organize thinking about a large number of pedagogically appropriate NOS ideas in terms of few inter-related categories. Because it is not prescriptive at the level of specifying curriculum and instructional actions, the FRA leaves educators with a wide range of choices regarding how to embed some of these ideas from each of the five categories in their teaching. This range of choices is advantageous because it does not mandate a specific set of ideas to be taught in relation to a given content, but invites the selection of relevant ideas along each category as they relate to the content. Educators seeking a short list of NOS statements to incorporate into classroom instruction will find instead guiding principles that need to be unpacked and embedded within the content they are teaching. These guiding principles are not declarative statements. They are contextual domains (cognitive, epistemic, social and institutional) that can be explored and translated into practical teaching and learning outcomes.

As for familiarity, the FRA deals with some commonly discussed themes in the science education literature, such as scientific practices, scientific methodology, and social certification. Some of the categories we introduced may seem either marginal or controversial to bring to students' attention. For example, the financial aspects of science and commodification of scientific knowledge discussed in Chap. 7 might communicate a rather pessimistic image of the scientific enterprise. The pedagogical implications of including or excluding such discussions in the classroom are addressed, but not necessarily settled.

In the end, we believe that more discussion and debate on these issues are needed beyond this book which is the starting, not the end point for a new debate on nature of science. Furthermore, it will be important to improvise effective models for communicating the notion of science as social system in school science especially with regards to how to balance its familiar components (e.g. socio-scientific issues) with less familiar ones (e.g. colonial science). Further research and development of models for incorporating these ideas into the core curriculum, instruction, and professional development will be needed. This is an ambitious task that can incorporate the work of many researchers who passionately believe that it is possible for students and teachers to access these ideas if we design the right curriculum materials and structure the appropriate learning environment to implement them.

It could be argued that applying the FRA to the curriculum might increase the cognitive demands on students and push the content beyond their reach. However, "cognitive development and educational psychology are converging on important conclusions that address policy concerns about STEM illiteracy. All show that we can teach science in a meaningful and better way, much earlier than we have—and that even preschool children have some relevant abstract abilities" (Vandell, Gelman, & Metz, 2010, p. 26). We extend the logic of this argument to maintain that when appropriate epistemic and social aspects are intertwined with the cognitive ones, they provide a stronger context and deeper meaning to the learning experience (Dagher, 2012). When these epistemic components are infused in a developmentally appropriate way, children will most likely understand them. A companion learning progression for these ideas can be developed in relation to the FRA, but this goes beyond the parameters of the present task.

The pedagogical demands that FRA might place on teachers may seem unreasonable. Teachers would need to know a lot more about how the FRA categories are contextualized for instance in the American context, within scientific practices, cross-cutting concepts and core ideas. Teachers need to have access to additional information, practical resources, and suggestions on how to promote more holistic discussions about nature of science. We acknowledge this to be a normal task that follows the introduction of new frameworks. What the FRA does is help teachers organize how they might draw on existing resources pertaining to each of the categories of the FRA. When internalized, the incorporation of these ideas is expected to flow out of planned inquiries into scientific practices, or discussions on how scientific knowledge is impacted by financial and other socio-cultural factors. Specific probes and supplements to activities can be added that promote the meta-cognitive thinking about these issues. Less important activities can be removed.

The effectiveness of the FRA model is yet to be investigated. The development of the FRA for educational use at this current stage is primarily conceptual and must be followed up with additional translational work that involves curriculum revision followed by empirical studies to determine optimal design of effective science curriculum and instruction. Interventions based on this framework need to be studied in terms of their effectiveness to improve students' understanding of nature of science and of science concepts. Our primary task in this book is to make the case that the expanded FRA can be a fruitful new conceptual territory that can redefine and rejuvenate research on the nature of science in science education. Adaptations of the examples presented throughout the book into empirical research will be crucial in illustrating the practical dimensions of the FRA model.

There are various possible processes and outcomes for how applications of the FRA can be characterized. It could be that we, as science educators, are borrowing from the work of philosophers of science in a way to repeat an existing framework for the purpose of generating a list of ideas for inclusion in science education. This sense of the application is about repetition of existing ideas for educational purposes. The primary outcome of this approach would be the generation of a list of concepts that are deemed to be useful for science education. A second approach could be translation of philosophical perspectives for use in science education. This sense of 'translation' would still yield a list as an outcome. However the list would be pedagogically mindful of how the philosophers' account maps to education, and it would be an applied list. A third sense of application concerns expansion of the philosophical work to have an original contribution. Here, the main outcome would be an extended list with new content. A fourth sense would involve the extension and translation where the now extended list is mapped to its pedagogical purposes.

A final sense of the way that philosophical analysis can be used for science education purposes concerns not just an extension and a translation of a set of original ideas but rather a complete transformation of a germ of an idea guided by pedagogical purposes where the key outcome now constitutes an original synthesis. It is in this final sense of the application of FRA to science education that we consider our work to be situated. In using, extending and transforming the original FRA, we are producing a new framework that has a different purpose and content as well as potential to redefine nature of science for science education. The original FRA is now reconfigured to project an image of science that is holistic but not normative in what it promotes for science teaching and learning. This image is not stagnant but is generative and malleable in nature, giving rise to multiple possibilities. The primary contribution of this approach is that the outcome of the application produces a set of heuristics that are not only epistemologically sound but are also pedagogically relevant and meaningful.

In summary, we propose the FRA as a practical conceptual tool to organize the infusion of various aspects of nature of science into the curriculum. Some of the ideas in each of the categories may apply to some science content, while others may apply better to other content. So while it is optimal that as many categories be addressed as possible when exploring a scientific unit of study, it is not necessary that the same level of depth be achieved for all components. It is to be expected that some will be addressed more than others on different occasions, but that over the school year or across grade levels, all aspects would have been addressed meaningfully and in context. Selecting and packaging FRA components to achieve specific NOS goals must be coordinated with other science education goals and with developmentally appropriate NOS content.

2.7 The Layout of the Book

In the rest of the book, a chapter is devoted to the discussion of each of the four categories under science as a cognitive-epistemic system, and one chapter for discussing the 11 categories under science as a social-institutional system. The discussions in each chapter are supplemented by instructional examples. In Chap. 3, we focus on aims and values and their role in science and emphasize their cognitive and epistemic aspects. In the discussion, following questions are explored: What are the aims and values of science? How do they guide scientific practices and theory choice? How do values influence the growth of scientific knowledge? Aims and values of science from various philosophical viewpoints are discussed and implications for science education are drawn. Furthermore, specific examples are drawn to demonstrate how scientific aims and values can be promoted in science lessons.

We discuss the range of scientific practices that scientists use in Chap. 4 where the following questions are addressed: What are the key epistemic, cognitive and social practices of science? How are these practices generated, evaluated and revised? The discussion is centered on three examples of scientific activities, namely classification, observation and experimentation. The choice of these activities rests on their prevalence in some version within the international science curricula. After reviewing select aspects of the nature of these activities, we illustrate how reflection on these scientific activities can be envisaged as part of a comprehensive model of scientific practices that would ensure that they are not visited in a fragmented fashion in science classrooms. A visual tool of scientific practices is proposed that consolidates some existing and contemporary accounts from curricular policy documents with implications for science curriculum and instruction.

After raising issues about the different ways by which the scientific method has been defined, Chap. 5 focuses on scientific methods and methodological rules. The question of what methods are best suited for investigating scientific problems in different domains is raised, and a pedagogical framework for communicating a range of scientific methods used in different science sub-disciplines is presented. A set of pedagogical strategies are proposed that can be used for promoting a concrete contextual understanding of the diversity of scientific methods. This chapter is particularly important in its clear depiction of the diversity of methods used in science which sits in contrast to the often over-emphasized and caricaturized image of the scientific method.

In Chap. 6, forms of scientific knowledge that include laws and models are described. The discussion is guided by the following questions: What are the different products of science? How are these forms of scientific knowledge related? How are they produced? What function/role do they play in the development of knowledge claims? Are there disciplinary variations in theories, laws, and models? What is the relationship of explanation to theories, models, and laws? Why is it useful for students to understand various forms of scientific knowledge? The chapter concludes by discussing ways for promoting discussions on the growth of scientific knowledge more systematically in educational contexts. Although school science is cluttered with scientific knowledge, often the processes of knowledge growth are not effectively articulated at the level of the classroom. As a result, students do not develop a sense of how scientific knowledge is generated, evaluated and revised throughout its development. Establishing some models of growth of scientific knowledge that can be effectively used in science lessons can help facilitate students' meaningful understanding of scientific knowledge.

Focusing on the four original FRA categories of science as a social-institutional system in Chap. 7, this dimension is extended to include three additional categories. After describing the system's components, we discuss a range of additional social conceptions of science that are not traditionally highlighted in school science. The following questions are addressed: What political, economical and sociological factors drive the scientific enterprise? How are scientists and communities of scientists influenced by such factors? The main purpose of this chapter, then, is to outline a set of social and institutional contexts that illustrate the scientific enterprise. Often in school science, the organizational and institutional aspects of science are particularly missing. For example, how scientists work in groups, the organizational and financial dynamics that govern scientists' behaviors and decision-making are not themes that are regularly captured in science lessons.

In Chap. 8, we revisit the FRA and its categories and how they work synergistically to provide a holistic account of science. The following questions are raised: What pedagogical strategies would go with which type of goal in these examples? How can teachers be supported in the development of their understanding and implementation of such holistic accounts of science? We also illustrate how using the FRA framework brings coherence to the science curriculum as it allows the adoption of effective teaching strategies based on decades of science education research. The connections between the FRA approach and the *Next Generation Science Standards* (NGSS Lead States, 2013) are explored given the timeliness of this document. Considering the impact of previous curriculum reform documents from the United States in the rest of the world, for instance the 1996 National Research Council published *National Science Education Standards*, it is likely that NGSS will gain much attention worldwide beyond the publication timeline of this book. Hence the intention is to offer some insight to the international science education research and policy audience regarding how our approach maps onto emerging curricular goals. The chapter concludes with a set of implications for an empirical research agenda.

We conclude this chapter with a word of caution. Irzik and Nola's (2014) version of the FRA includes eight-categories, and our extension leads to 11. The suggestion is not a replacement of an existing NOS "consensus view" that practically relies on a set of seven tenets, for instance, with a set of 11 categories. The approach in the application of FRA is more nuanced in the following way. First, the adaptation of the FRA is made with appeal to theoretical arguments on 'science' based on contemporary research philosophy of science. Second, the transformation of FRA principles to science education practice is based on our understanding of cognitive science and science education research which have provided a solid knowledge base of what students and teachers know and are capable of doing. We also base it on our collective experience (four decades), in the field and keen awareness of exemplary teaching practices. Third, rather than listing a set of NOS learning objectives focusing on a limited set of ideas, overarching principles are outlined from which objectives can be drawn and adapted to different settings and grade levels. The overarching principles invite teachers and teacher educators to be creative participants in seizing opportunities for discussing the nature of science, in context, along the 11 categories highlighted in this book.

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