Chapter 8
Investigating the Epistemic Nature of STEM: Analysis of Science Curriculum Documents from the USA Using the Family Resemblance Approach

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Contents

8.1 Introduction

Science, Technology, Engineering and Mathematics (STEM) education has been ubiquitous in recent curriculum policy and research literature during the past two decades (National Science and Technology Council, 2013; The Royal Society Science Policy Centre, 2014). It mainly has been advocated as an instructional approach that integrates different disciplines of human knowledge (Brown, Brown, Reardon, & Merrill, 2011; Bybee, 2010; Honey, Pearson, Schweingruber, and National Academy of Engineering,, and National Research Council, 2014), while the precise epistemic nature of STEM and how such epistemic nature applies in education remain relatively understudied (Chesky & Wolfmeyer, 2015). By "epistemic nature" we mean not only the characteristics of STEM knowledge but also the processes through which STEM knowledge is produced, evaluated and revised (Erduran & Dagher, 2014a; Hodson, 2014). An epistemic perspective on STEM

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may help to highlight the shared features of the component STEM disciplines as well as differences among them. For example, all STEM disciplines might strive to achieve objectivity in their respective fields, but not all STEM disciplines share the same characterisations of what counts as a theory. What an engineer mean by a theory may not necessarily correspond to what a biologist might mean by the same term.

In this chapter, we use the framework of the Family Resemblance Approach (Erduran & Dagher, 2014a; Irzik & Nola, 2011) as a basis for highlighting the epistemic similarities and differences between the constituent STEM disciplines as represented in key science curriculum documents. FRA presents the possibility to consider STEM as a cognitive-epistemic and social-institutional system whereby each constituent discipline is contrasted relative to aims, values, practices, norms, knowledge, methods and social context. Drawing on Wittgenstein's linguistic philosophy, FRA allows for comparing and contrasting constituent disciplines of STEM as members of a "family" that share particular features but also highlights domain specificity where particular knowledge and practices are specific to the respective discipline. We focus on the *epistemic* components of each disciplinary system, highlighting the theoretical framework on the aims and values, practices, methods and knowledge. The aim is to help curriculum makers and teachers to recognise epistemic underpinnings of STEM disciplines and their importance in integrating STEM in both curriculum and pedagogy.

After laying out the background and main ideas of FRA, we present an analysis of two curriculum policy documents, the *Science for All Americans* (SfAA) (AAAS, 1989) and the *Next Generation Science Standards* (NGSS) (NGSS Lead States, 2013), to examine their respective coverage of epistemic aspects of STEM. As a vision document, SfAA identifies what is important for the next generation to be scientifically literate and highlights the connections among the natural and social sciences, mathematics and technology. On the contrary, NGSS is a standards document and comprises performance expectations which incorporate all three dimensions from the science and engineering practices, core disciplinary ideas and crosscutting concepts. We selected these two documents to illustrate from the standpoint of science education how the epistemic aspects of STEM in different formats of curriculum documents could be analysed and to draw implications for curriculum policy with regard to integrated STEM education. Although we focus on the science curriculum documents in this chapter, similar analyses can be made to the curriculum documents in the other disciplines to inform STEM integration in each disciplinary context. The analysis was guided by our research question: What epistemic natures of STEM disciplines are addressed in the two key science curriculum reform documents?

8.2 Epistemic Nature of STEM

The history of science curriculum profoundly reveals a persistent tension between the products of science (i.e. scientific knowledge) and the process through which it is generated and accepted. Since the early twentieth century, when British science educator Henry Armstrong called for the inclusion of "scientific method" as a core curricular component (Armstrong, 1910), science educators have emphasised "scientific inquiry" (Schwab, 1958), "procedural knowledge" (Black, 1990) and "scientific practice" (NGSS Lead States, 2013)—all of which concerns how scientific knowledge is generated, evaluated and shared, albeit with varying motivations and focuses. Underlying these emphases was a shared belief that the epistemic aspects of science should be made explicit throughout all levels of formal education (Gott & Murphy, 1987; Osborne, 2016), in addition to scientific content knowledge. Infusing the epistemic nature of science has been advocated for its benefits in enhancing students' understanding of scientific objects and processes, informed decision making, responsible citizenship and so on (Driver, Leach, Millar, & Scott, 1997; Hodson, 2014; Lederman, 2007). At the same time, research has suggested that these epistemic aspects are not naturally learned by simply engaging in the disciplinary practices (Bell, Mulvey, & Maeng, 2016; Pleasants & Olson, 2018) but should be instructed in an explicit teaching approach (Abd-El-Khalick, 2005; Akerson, Abd-El-Khalick, & Lederman, 2000).

The emphasis on the context of disciplinary knowledge production has not been limited to science education. In technology education, nature of technology (NOT) and nature of engineering (NOE) have recently been established as a research and policy theme (Clough, Olson, & Niederhauser, 2013; International Technology Education Association, 2007; National Academy of Engineering, 2010; National Academy of Sciences & National Academy of Engineering, 2009; National Research Council, 2012). What is technology? What do engineers do? How does technology relate to society? These questions have stimulated technology educators' interest in the distinct features of technology to be included in the curriculum (De Vries, 2005; DiGironimo, 2011; Gil-Pérez et al., 2005; Pleasants & Olson, 2018; Waight, 2014) and teachers' and students' ideas about these features (Fralick, Kearn, Thompson, & Lyons, 2009; Hammack, Ivey, Utley, & High, 2015; McRobbie, Ginns, & Stein, 2000; Rennie, 1987). Similarly, the epistemic nature of mathematics (NOM) has been of interest to a number of mathematics educators, most frequently with respect to how teachers' beliefs about mathematics influence their teaching practice (Collier, 1972; Ernest, 1989a; Handal, 2003; Shahbari & Abu-Alhija, 2018).

One interesting observation here is that while some epistemic features of different disciplines are very similar, others seem to be applicable only to a subset of STEM. For example, scientific knowledge and technological knowledge are similar in that they both rely on mathematical relationships and are subject to change and are fallible. However, as de Vries (2005) sharply noted, on the fundamental level, technological knowledge is distinguished from scientific knowledge in terms of its "normative" character, in that knowing technology encompasses making "judgements" about the functions and processes. Also, optimisation of solutions is much more important in engineering than in pure science (Pleasants & Olson, 2018). What makes the situation even more complex is that such disciplinary divergence in terms of epistemic practices occurs even *within* natural sciences and also varies from research group to research group. A notable example is found in Galison's (1997) study of twentieth-century high-energy physics, where he demonstrated that physicists in different research traditions use different forms of arguments to support their claims. These complexities suggest that similarities and differences should be a central theme for understanding and describing "epistemic nature" of STEM in schools (Broggy, O'Reilly, & Erduran, 2017; Hodson, 2014; Irzik & Nola, 2014; Park & Song, 2019). In what follows, we suggest the Family Resemblance Approach (FRA) as a conceptual lens to view the diverse epistemic nature of the STEM disciplines, and we utilise it to examine two science curriculum documents from the USA.

8.3 Theoretical Framework: Family Resemblance Approach (FRA)

The concept of family resemblance has its origin in the German philosopher Ludwig Wittgenstein's linguistic philosophy (Wittgenstein, 1953/2009). Using the example of the word "game", Wittgenstein argued that a concept cannot be defined by a certain set of necessary and sufficient conditions—some games are not competitive, some are not entertaining, and some are without rules. Instead, a word is "a complicated network of similarities overlapping and criss-crossing" (Wittgenstein, 1953/2009, p. 36). A decade later, Thomas Kuhn took up the family resemblance concept in his seminal work *The Structure of Scientific Revolutions* (Kuhn, 1962/2012) to describe the scientific practice. An established scientific tradition, Kuhn explained, can be identified:

> … by resemblance and by modelling to one or another part of the scientific corpus which the community in question already recognises as among its established achievements [but not by] some explicit or even some fully discoverable set of rules and assumptions that gives the tradition its character and its hold upon the scientific mind. (Kuhn, 1962/2012, p. 45)

In the 2010s, FRA has drawn attention in the field of science education as a tool to conceptualise and portray NOS. Irzik and Nola (2014) understand science in terms of its *cognitive-epistemic* (aims and values, methods and methodological rules, process of inquiry, knowledge) and *social-institutional* characteristics (professional activities, social certification and dissemination, social values, scientific ethos). Irzik and Nola's framework is based on the idea that these eight categories can be used as a lens to understand the similarities and differences among scientific domains such as astronomy, experimental physics and molecular biology (Irzik & Nola, 2014). They described science as:

> a cognitive and social system whose investigative activities have a number of aims that it tries to achieve with the help of its methodologies, methodological rules, system of knowledge certification and dissemination in line with its institutional social-ethical norms, and when successful, ultimately produces knowledge and serves society. (Irzik & Nola, 2014, p. 1014)

Defining science this way allows revealing both the domain-general and domain-specific aspects of science in a holistic and coherent manner. FRA as an approach to NOS is gaining increasing attention among science educators (e.g. Alsop & Gardner, 2017; Hodson & Wong, 2017). Recently, Erduran and Dagher (2014a) significantly extended the original account of FRA and added three new categories—political power structures, financial systems and social values—which are becoming more significant in the contemporary scientific practice (see Table 8.1).

Table 8.1 Descriptions of the 11 FRA categories

Category	Description	Keywords
Aims and values	The key cognitive and epistemic objectives of STEM, such as accuracy and objectivity	Aim, value, goal, accuracy, objectivity
Methods	The manipulative as well as non-manipulative techniques that underpin STEM research	Method, scientific method, inquiry, process, hypothesis, manipulation of variables
Practices	The set of epistemic and cognitive practices that lead to STEM knowledge through social certification	Observation, experimentation, data, explanation, model, argumentation, classification, prediction
Knowledge	Theories, laws and explanations that underpin the outcomes of STEM inquiry	Knowledge, scientific knowledge, formulation of knowledge, theory, law, model
Social certification and dissemination	The social mechanisms through which STEM professionals review, evaluate and validate knowledge, for instance, through the peer review systems of journals	Peer review, validate, evaluate, certification, dissemination, collaboration
Ethos	The norms that STEM professionals employ in their work as well as in interaction with colleagues	Scientific norms, ethics, bias, being sceptical, caution against bias
Social values	Values such as freedom, respect for the environment and social utility	Culture, cultural, social values, society, beliefs, freedom, respect
Professional activities	How STEM professionals engage in professional settings such as attending conferences and doing publication reviews	Conference, article, presentation, writing, publishing, publication
Social organisations and interactions	How STEM is arranged in institutional settings such as universities and research institutes	University, research centre, institution, organisation
Financial systems	The underlying financial dimensions of STEM, including funding mechanisms	Financial, funding, finance, economy, economical, budget
Political power structures	The dynamics of power that exist between STEM professionals and within disciplinary cultures	Political power, research team, team leader, team members, researcher, gender, ethnicity, race, nationality

Adapted from (Erduran & Dagher, 2014a)

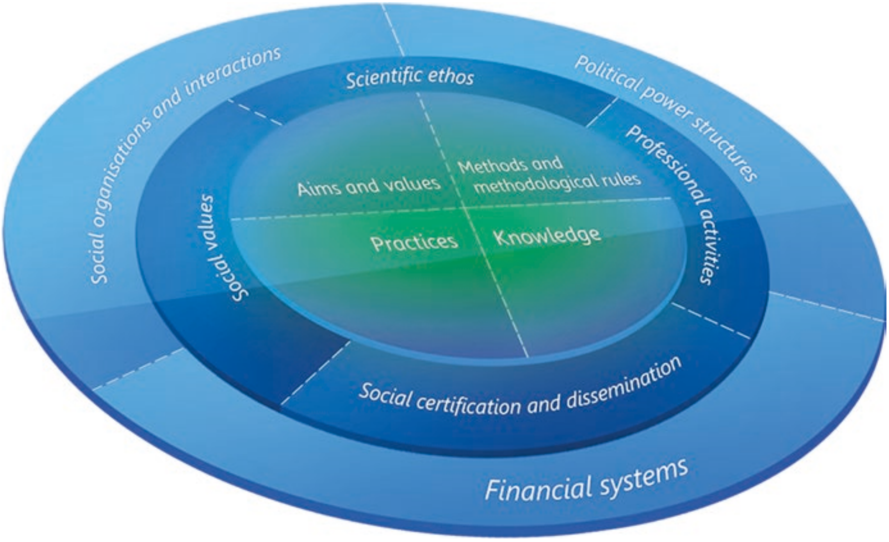

Fig. 8.1 FRA wheel: science as a cognitive-epistemic and social-institutional system (Reprinted with permission from Erduran & Dagher, 2014a, p. 28)

An aspect of Erduran and Dagher's work is that it includes visual images as well as other pedagogical adaptations of FRA ideas to make the approach more relevant and applicable to science education (Erduran, 2017; Erduran & Kaya, 2018). There is now considerable number of studies that have used FRA in science education, for example in the context of science teacher education (e.g. Erduran, Kaya, Cilekrenkli, Akgun & Aksoz, 2020; Petersen, Herzog, Path & FleiBner, 2020), undergraduate education (Akgun & Kaya, 2020) as well as textbook (Park, Seinguran & Song, 2020) and curriculum (Cheung, 2020) analysis. As an example, the FRA wheel (see Fig. 8.1) provides a visual and holistic model to capture diverse NOS aspects, instead of a set of specific NOS statements to be transmitted to students. FRA itself does *not* provide, for example, some universally valid tenets about scientific methods or practices. Instead, FRA offers "a broader and more inclusive framework to capture various aspects of NOS, rather than discrete ideas about NOS tenets" (Kaya & Erduran, 2016). This characteristic of FRA as a "heuristic" makes it particularly suitable for comparing and contrasting diverse areas of human knowledge such as STEM. In the following, we use FRA to analyse SfAA and NGSS as examples of science curriculum documents to exemplify the potential of FRA in informing curriculum policy and practice.

8.4 Epistemic Nature of STEM Disciplines in SfAA and NGSS

Curriculum documents as the guidelines for designing curriculum materials, planning instruction and assessing student performance are important to be studied, because they reflect not only the core interest of the curriculum makers but also their potential impact on teaching practice in schools (Olson, 2018). Olson (2018) examined nine science curriculum documents and found that NOS was insufficiently stated in these countries' documents. Previous studies have demonstrated the contribution of the FRA framework as an analytical tool not only in facilitating science curriculum analysis but also in determining the gaps related to the NOS in the curriculum, such as NGSS in the USA (Erduran & Dagher, 2014a), the *Junior Cycle Draft Specifications* in Ireland (Erduran & Dagher, 2014b; Kelly & Erduran, 2018) and Turkish national science curricula from 2006 and 2013 (Kaya & Erduran, 2016). The findings of Kaya and Erduran (2016) indicated that the Turkish curricula underemphasise the social-institutional aspects of science, suggesting a need for further efforts. More recently, Park, Wu and Erduran (2020) used FRA to compare how recent science education standards documents from the USA, Korea and Taiwan portray the aims, values and practices of STEM disciplines. Their analysis showed a general lack of mathematics-related features in the documents and the variations across the three countries.

8.4.1 Curriculum Documents

To demonstrate the potential of the FRA framework in revealing and informing the representation of the nature of STEM, SfAA and NGSS were selected for analysis. SfAA was published as an early-stage outcome of *Project 2061* of the American Association for the Advancement of Science in an effort to initiate significant and lasting improvements in science education. Setting out what constitutes scientific literacy for the next generation, SfAA has since functioned as a basis for a number of science curriculum documents in the USA. In 2013, NGSS came out as the result of a multi-state effort to develop new standards that are "rich in content and practice, arranged in a coherent manner across disciplines and grades to provide all students an internationally benchmarked science education" (NGSS Lead States, 2013, p. xiii). Since its release, NGSS has been widely influencing the science curricula and classroom practices both in the USA and internationally (Sadler & Brown, 2018). We selected these two documents because they reflect what US science curriculum makers thought to be most important things to know in 1989 and 2013, respectively. Besides, since SfAA sets out the visions for science education, while NGSS represents the standards for ideas and practices that scientifically literate citizens should know, comparing the two can show how the emphasis has changed (or not) over time between the two distinct types of curriculum documents.

Table 8.2 shows the structure of SfAA and NGSS. The table shows that both documents include sections that connect science to its neighbour disciplines and the ones that address the epistemic nature of these disciplines, although neither SfAA nor NGSS explicitly mentions “STEM integration” anywhere in the documents. In SfAA, references to the nature of STEM disciplines are concentrated in Chapters 1 through 3, while in NGSS, references are made in both the standards and the appendixes. To get a holistic understanding of each document in terms of the nature of STEM disciplines, we included the entire document for analysis, including the appendixes, and front and back matters.

Table 8.2 Structure of SfAA and NGSS

SfAA	NGSS
Front matter	Volume 1: The standards—arranged by disciplinary core ideas and by topics
Recommendations for science literacy	Front matter
1. The nature of science	NGSS arranged by disciplinary core ideas
2. The nature of mathematics	NGSS arranged by topics
3. The nature of technology	Volume 2: Appendixes
4. The physical setting	Front matter
5. The living environment	A. Conceptual shifts in NGSS
6. The human organism	B. Responses to the public drafts
7. Human society	C. College and career readiness
8. The designed world	D. “All standards, all students”: Making NGSS accessible to all students
9. The mathematical world	E. Disciplinary core idea progressions in NGSS
10. Historical perspectives	F. Science and engineering practices in NGSS
11. Common themes	G. Crosscutting concepts in NGSS
12. Habits of mind	H. Understanding the scientific enterprise: The nature of science in NGSS
Bridges to the future	I. Engineering design in NGSS
13. Effective learning and teaching	J. Science, technology, society and the environment
14. Reforming education	K. Model course mapping in middle and high school for NGSS
15. Next steps	L. Connections to the common core state standards for mathematics
Back matter	M. Connections to the common core state standards for literacy in science and technical subjects

8.4.2 Content Analysis

In line with similar studies (Erduran & Dagher, 2014a, 2014b; Kaya & Erduran, 2016), we used the descriptions of each category and a set of keywords to identify indicative statements of NOS, NOT, NOE and NOM in the two documents (Table 8.1). When the statements contained the keywords or similar words to imply the relationships between the performance expectations and the nature of features in the FRA categories, they were coded to the corresponding category. For example, the statement "Science investigations are guided by a set of values to ensure accuracy of measurements, observations and objectivity of findings" in NGSS (Appendix H, p. 98) was identified as a reference to aims and values of science. However, statements that did not conform to the FRA definitions were not coded, even if they included some of the keywords.

Instead of counting how many times each category is addressed in the documents, we looked at whether the respective categories are being addressed at least once and, if so, what are the salient features being represented. This was because we were interested in the qualitative representation of each epistemic category rather than the frequency of references made to the categories. The analysis was conducted by two coders. Each coder coded SfAA and NGSS individually and selected the exemplary statements that showed each document's description of the epistemic aspects of STEM. Any disagreements in coding were resolved through discussion between the coders.

8.4.3 Findings

The results of the analysis on SfAA and NGSS are shown in Tables 8.3 and 8.4. The existence of at least one instance of a category is noted in the tables. As the tables indicate, most categories have instances except for practices of technology and methods of mathematics in NGSS. The following paragraphs illustrate example excerpts to provide a qualitative indication of how the documents address each category.

First, in the case of NOS, "accuracy" appears in both SfAA and NGSS as an epistemic aim of science (see Table 8.5). With respect to methods, SfAA is more nuanced in terms of the kind of methodological approaches science utilises. For instance, SfAA makes reference to hypothesis as well as quantitative and qualitative methods, while NGSS is fairly broad in its depiction of methods in terms of measurements and observations. In terms of scientific practices, both documents refer to similar concepts such as evidence, explanations and predictions, all of which were suggested as important practices of science in Erduran and Dagher (2014a). While SfAA refers to scientific knowledge in a fairly generic sense and describes its tentativeness, limitation and universality, NGSS details the kinds of scientific knowledge in terms of theories and laws and explains what they are. Despite these minor varia-

Table 8.3 Distribution of epistemic categories in SfAA

Epistemic category	NOS	NOT	NOE	NOM
Aims and values	+	+	+	+
Methods	+	+	+	+
Practices	+	+	+	+
Knowledge	+	+	+	+

Table 8.4 Distribution of epistemic categories in NGSS

Epistemic category	NOS	NOT	NOE	NOM
Aims and values	+	+	+	+
Methods	+	+	+	
Practices	+		+	+
Knowledge	+	+	+	+

tions, NOS is generally well represented in SfAA and NGSS, which is unsurprising given the richness of the discussion on NOS in science education community during the past three decades (Hodson, 2014; Lederman, 2007).

In the case of NOT, both SfAA and NGSS refer to the utility of technology in society as its core value (see Table 8.6). While SfAA focuses on the role of probability and risk in the context of aims and values of technology, NGSS emphasises the role of engineering design. NGSS does not refer to particular practices in relation to technology, whereas SfAA refers to mathematical models in the context of computer technology. The focus on materials in the development of knowledge in technology is evident in NGSS, whereas the emphasis in the case of SfAA seems to be primarily on scientific knowledge.

The epistemic features of engineering are covered in both SfAA and NGSS, although NGSS has much more detail and nuance to how engineering practices work in all categories except for methods (see Table 8.7). When describing the aims of engineering, both documents stressed finding solutions to practical problems as its main goal, as opposed to science being primarily interested in providing explanations. Also, they both highlighted that engineers rely on science and technology to accomplish their aims. A significant variation between the two documents is the reference to practices such as argumentation and modelling. In parallel with NGSS's emphasis on scientific and engineering practices (NGSS Lead States, 2013, Appendix F), it delineates the centrality of argumentation and reasoning in engineering as well as in science and also explicitly states that these practices are shared between the two disciplines. Such an emphasis reflects science educators' increasing interest in argumentation as a core practice across school subjects (Erduran, Guilfoyle, Park, Chan, & Fancourt, 2019; Fischer, Chinn, Engelmann, & Osborne, 2018). On the contrary, SfAA refers to several steps of engineering design such as constructing problems and testing without comparing them to practices in other disciplines.

Finally, in the case of NOM, a significant observation is that NGSS does not explicitly refer to the methods of mathematics (i.e. how mathematical inquiry is carried out), while there is some reference to them in SfAA (see Table 8.8). When it

Table 8.5 Examples of NOS in SfAA versus NGSS

Epistemic category	SfAA	NGSS
Aims and values	Scientists try to identify and avoid bias. (p. 6) Scientists assume that even if there is no way to secure complete and absolute truth, increasingly accurate approximations can be made to account for the world and how it works (p. 2)	Science investigations are guided by a set of values to ensure accuracy of measurements, observations and objectivity of findings. (Appendix H, p. 98)
Methods	Fundamentally, the various scientific disciplines are alike in their reliance on evidence, the use of hypothesis and theories, the kinds of logic used and much more. (p. 3) … they place on historical data or on experimental findings and on qualitative or quantitative methods There simply is no fixed set of steps … (p. 4)	Science investigations use a variety of methods and tools to make measurements and observations. (Appendix H, p. 98)
Practices	Science demands evidence. (p. 4) Science is a blend of logic and imagination. (p. 5) Science explains and predicts. (p. 6) Scientists see patterns in phenomena as making the world understandable. (p. 27)	Science is both a body of knowledge and the processes and practices used to add to that body of knowledge. (Appendix H, p. 100) A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that has been repeatedly confirmed through observation and experiment. (Appendix H, p. 99)
Knowledge	Scientific ideas are subject to change. (p. 29) Scientific knowledge is durable. (p. 3) Science cannot provide complete answers to all questions. (p. 3)	Science knowledge is based upon logical and conceptual connections between evidence and explanations. (Appendix H, p. 98)
	Science also assumes that the universe is, as its name implies, a vast single system in which the basic rules are everywhere the same. Knowledge gained from studying one part of the universe is applicable to other parts. (p. 2)	Scientific theories are based on a body of evidence developed over time. (Appendix H, p. 99) Laws are regularities or mathematical descriptions of natural phenomena. (Appendix H, p. 99)

comes to the aims and values, SfAA describes at several places what mathematics is, what mathematicians seek to discover and both the intrinsic values (e.g. “its beauty and its intellectual challenge” [p. 15] and “the greatest economy and simplicity” [p. 16]) and its utility in the context of other disciplines such as science and engineering. On the contrary, NGSS only provides a limited account of what math-

Table 8.6 Examples of NOT in SfAA versus NGSS

Epistemic category	SfAA	NGSS
Aims and values	In the broadest sense, technology extends our abilities to change the world: to cut, shape, or put together materials; to move things from one place to another; to reach farther with our hands, voices, and senses (p. 25)	The uses of technologies and any limitations on their use are driven by individual or societal needs, desires and values; by the findings of scientific research; and by differences in such factors as climate, natural resources and economic conditions. Thus technology use varies from region to region and over time. (p. 57)
Methods	Analysis of risk, therefore, involves estimating a probability of occurrence for every undesirable outcome that can be foreseen—and also estimating a measure of the harm that would be done if it did occur. (p. 32)	Scientific discoveries about the natural world can often lead to new and improved technologies, which are developed through the engineering design process. (p. 25)
Practices	Using mathematical models of wave behavior, computers are able to process information from these probes to produce moving, three-dimensional images. (p. 124)	None found
Knowledge	But just as important as accumulated practical knowledge is the contribution to technology that comes from understanding the principles that underlie how things behave—that is, from scientific understanding. (p. 26)	Every human-made product is designed by applying some knowledge of the natural world and is built using materials derived from the natural world. (p. 174)

ematics is for by describing it as a "fundamental tool" for representing variables and relationships in science and engineering (Appendix F, p. 68). Similarly, there is much more coverage of types of mathematical knowledge such as theories in the case of SfAA, while NGSS is fairly limited in its discussion of the nature of mathematical knowledge, particularly how knowledge is generated and relates to other knowledge in mathematics. In summary, NGSS includes much less descriptions of mathematics as an academic discipline, although it acknowledges the close relationship between science and mathematics (NGSS Lead States, 2013, p. 138).

8.5 Implications for Curriculum Policy in STEM Education

While numerous arguments have been advanced for the inclusion of an integrated STEM in school curricula worldwide, the precise nature of these inclusions needs further articulation. In this chapter, we addressed the epistemic dimension of technology, engineering and mathematics to be included in the science curriculum. A

Table 8.7 Examples of NOE in SfAA versus NGSS

Epistemic category	SfAA	NGSS
Aims and values	Engineers use knowledge of science and technology, together with strategies of design, to solve practical problems. (p. 26) Engineering combines scientific inquiry and practical values. (p. 27)	The end-products of science are explanations and the end-products of engineering are solutions. (Appendix F, p. 74)
	One goal in the design of such devices is to make them as efficient as possible—that is, to maximise the useful output for a given input (p. 117)	The goal of engineering design is to find a systematic solution to problems that is based on scientific knowledge and models of the material world. Each proposed solution results from a process of balancing competing criteria of desired functions, technical feasibility, cost, safety, aesthetics and compliance with legal requirements. The optimal choice depends on how well the proposed solutions meet criteria and constraints. (Appendix F, p. 75)
Methods	The basic method is to first devise a general approach and then work out the technical details of the construction of requisite objects (such as an automobile engine, a computer chip, or a mechanical toy) or processes (such as irrigation, opinion polling, or product testing). (p. 27)	Scientific discoveries about the natural world can often lead to new and improved technologies, which are developed through the engineering design process. (p. 25)
Practices	In its broadest sense, engineering consists of construing a problem and designing a solution for it. (p. 27)	In science and engineering, reasoning and argument based on evidence are essential to identifying the best explanation for a natural phenomenon or the best solution to a design problem. (Appendix F, p. 62)
	Designs almost always require testing, especially when the design is unusual or complicated, when the final product or process is likely to be expensive or dangerous, or when failure has a very high cost. (p. 29)	Scientists and engineers engage in argumentation when investigating a phenomenon, testing a design solution, resolving questions about measurements, building data models and using evidence to evaluate claims. (Appendix F, p. 62) Like scientists, engineers require a range of tools to identify patterns within data and interpret the results. Advances in science make analysis of proposed solutions more efficient and effective. (Appendix F, p. 72)

(continued)

Table 8.7 (continued)

Epistemic category	SfAA	NGSS
Knowledge	Engineers use knowledge of science and technology, together with strategies of design, to solve practical problems. (p. 26)	Modelling tools are used to develop questions, predictions and explanations; analyse and identify flaws in systems; and communicate ideas. Models are used to build and revise scientific explanations and proposed engineered systems. Measurements and observations are used to revise models and designs. (Appendix F, p. 68)

recent framework to the nature of science in science education concerns the so-called Family Resemblance Approach which inherently places an emphasis on the epistemic categories of science. Hence, we capitalised on this framework to explore the epistemic aims, values, methods, practices and knowledge accounts in relation to nature of science, technology, engineering and mathematics as advanced in high-profile and influential science curriculum documents of SfAA and NGSS.

In general, our result indicates that both documents have some references to most epistemic categories of STEM disciplines. However, several curricular omissions including the neglect of NOM suggest that the documents have limitation in addressing the epistemic aspects in a balanced and coherent manner. While there are many similarities between SfAA and NGSS (e.g. advocating the epistemic aim of "accuracy" in science), SfAA seems more nuanced in some aspect while NGSS in others. For example, while SfAA is more nuanced in terms of the kind of methodological approaches science utilises (e.g. reference to hypothesis as well as quantitative and qualitative methods), NGSS details the kinds of scientific knowledge in terms of theories and laws in a more thorough manner. With respect to a contrast of the reference to technology and engineering, NGSS seems to place more emphasis on engineering design, and extensive reference is devoted to engineering practices. A significant variation between the two documents is the reference to practices such as argumentation and modelling. Finally, in the case of NOM, a significant observation is that NGSS does not explicitly refer to the methods of mathematics, while there is some reference to this category in SfAA (see Table 8.8). There is much more coverage of types of mathematical knowledge such as theories in the case of SfAA, while NGSS is fairly limited in its discussion of the nature of mathematical knowledge.

Part of the differences between SfAA and NGSS can be explained in terms of the different purposes of the two documents, the former being the statement of higher-level visions for science education and the latter a set of concrete standards for curriculum development and classroom practice. However, the comparison also tells us much about how the focus of the US science curriculum documents has changed over the two decades with regard to the nature of STEM disciplines, while the abstract ideals and visions were translated into more concrete curriculum standards. Our analysis shows that there are many places where NGSS elaborates on the visions set out in SfAA (e.g. the relationship between science and engineering), but it also suggests that several important ideas of SfAA has been lost in NGSS (e.g. the

Table 8.8 Examples of NOM in SfAA versus NGSS

Epistemic category	SfAA	NGSS
Aims and values	Mathematics relies on both logic and creativity, and it is pursued both for a variety of practical purposes and for its intrinsic interest. For some people, and not only professional mathematicians, the essence of mathematics lies in its beauty and its intellectual challenge. For others, including many scientists and engineers, the chief value of mathematics is how it applies to their own work. (p. 15) Part of the sense of beauty that many people have perceived in mathematics lies … in finding the greatest economy and simplicity of representation and proof. (p. 16)	In both science and engineering, mathematics and computation are fundamental tools for representing physical variables and their relationships. (Appendix F, p. 68)
Methods	Mathematical thinking often begins with the process of abstraction—that is, noticing a similarity between two or more objects or events. (p. 19) Mathematical processes can lead to a kind of model of a thing, from which insights can be gained about the thing itself. (p. 20)	None found
Practices	Using mathematics to express ideas or to solve problems involves at least three phases: (1) representing some aspects of things abstractly, (2) manipulating the abstractions by rules of logic to find new relationships between them and (3) seeing whether the new relationships say something useful about the original things. (p. 19) As a theoretical discipline, mathematics explores the possible relationships among abstractions without concern for whether those abstractions have counterparts in the real world. (p. 16)	Mathematical and computational approaches enable scientists and engineers to predict the behaviour of systems and test the validity of such predictions. (Appendix F, p. 73)
Knowledge	Mathematicians, like other scientists, are particularly pleased when previously unrelated parts of mathematics are found to be derivable from one another, or from some more general theory. (p. 16) A central line of investigation in theoretical mathematics is identifying in each field of study a small set of basic ideas and rules from which all other interesting ideas and rules in that field can be logically deduced. (p. 16)	Laws are regularities or mathematical descriptions of natural phenomena. (Appendix H, p. 99)

nature of mathematics as a discipline and the interdependence of science, technology, engineering and mathematics). Given the rise of STEM education and the increasing interest in teaching the nature of the disciplines, more explicit consideration of the nature of STEM would be crucial in developing future curricula.

In this chapter, we drew on the recent discourse on the nature of science to shed light on the epistemic aspects of STEM disciplines and their potential importance in integrated approaches to STEM education. More specifically, we highlighted how the FRA can point to specific curriculum emphases and omissions with respect to the epistemic nature of STEM. This way, FRA allowed us to illustrate what were the epistemic aspects of each discipline being highlighted in the curriculum document. Such information can be used for effective curriculum development and eventual implementation of STEM in teaching and learning such that there is coherence in how STEM domains are represented (Yeh, Erduran & Hsu, 2019). FRA not only provides a useful analytical tool for tracing curriculum content but also has the potential to clarify the epistemic foundations of STEM. While we focused on two key curriculum documents for K-12 science in this chapter, FRA would be a useful tool for analysing mathematics, technology and engineering curricula as well. For example, given that understanding the mathematical practice has emerged as one key goal of school mathematics (Ernest, 1989b; François & van Bendegem, 2007), it would be necessary for K-12 mathematics curricula to include how mathematics as a discipline operates in a broader enterprise of STEM and how it relates to the other three disciplines in terms of each epistemic categories of FRA. In this sense, FRA provides a useful lens for incorporating the rich discussion in the philosophy of mathematics (Ernest, 1989b), and of technology (Waight, 2014; Waight & Abd-El-Khalick, 2012) and engineering (Antink-Meyer & Brown, 2019; Pleasants & Olson, 2018) into curricular content that is suitable for students.

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