0 A Cognitive and Epistemic Account of the Nature of Engineering

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Abstract Educators and policymakers advocate the need for developing engineering literacy among school students, yet there is an ongoing debate related to the conceptualization of the 'Nature of Engineering' and the heuristics that should be applied. Thus, the goal of this chapter is to provide a theoretical ground for a nuanced conceptualization of the Nature of Engineering while drawing on aspects of the Nature of Science through the application of the Family Resemblance Approach. We review and discuss current studies on school engineering education and the integration of engineering into the science curriculum. We describe four aspects of engineering fields: Structures, Machines, Materials, and Data, each uniquely characterized by the technology used and the artifact produced. Focusing on the Family Resemblance Approach's cognitive-epistemic domain, we describe the Nature of Engineering through four categories: Aims & Values, Engineering Practices, Methods & Methodological Rules, and Engineering Knowledge, which can guide the integration of engineering education in schools.

Keywords Engineering Literacy, Family Resemblance Approach, Nature of Engineering (NOE)

Introduction

In recent years, there has been a notable increase in interest and research focus on pre-college engineering education within the realms of science and engineering pedagogy (Cunningham et al., 2020; NASEM, 2020; Purzer et al., 2022). This growing attention highlights a shared recognition among educators and policymakers of the necessity to cultivate an understanding of engineering and its societal impact within K-12 education (AE3 & ASEE, 2020; Antink-Meyer &

Brown, 2019; McComas & Burgin, 2020; NGSS Lead States, 2013; Parrish et al., 2024; Purzer et al., 2022).

The significance of engineering education can be attributed to three main dimensions: Firstly, engineering literacy is essential in navigating a world increasingly driven by technology (Carr et al., 2012; NAGB, 2018; NGSS Lead States, 2013; NRC 2012). Secondly, engineering encapsulates critical skills such as problem-solving, systems thinking, and innovation, which are vital for the sustainable development of contemporary society (Barak & Yuan, 2021; NASEM, 2020; Purzer et al., 2022). Thirdly, persistent shortages in engineering talent, coupled with the designation of engineering occupations as priority fields, underscore the pressing need for robust engineering education (NAGB, 2018; NASEM, 2020).

Nevertheless, debates persist around key inquiries such as: What should comprise the core concepts and skills of engineering education in schools? Which pedagogical methodologies should be employed? Where within the K-12 curriculum should engineering be integrated? What qualifications are requisite for teaching engineering effectively? These questions remain pertinent, fueling ongoing discussions among science and engineering scholars (e.g., Cunningham et al., 2020; Deniz et al., 2020; McComas & Burgin, 2020; Parrish et al., 2024; Purzer et al., 2022).

From a historical point of view, engineering has been an intrinsic facet of human civilization since ancient times, as evidenced by the invention of tools to facilitate daily life. The term 'Engine' originates from the Latin 'Ingenium', denoting mental prowess or clever invention. Derived from this is 'Engineer', a term dating back to the 14th century, signifying an individual involved in constructing and operating military machinery (i.e., engines). Across epochs, engineering has been synonymous with the creation and refinement of artifacts to enhance human functionality (Kroes, 2012; Mitcham & Schatzberg, 2009). However, it is imperative to acknowledge that while engineering innovations may enrich our lives, they can also pose risks, exemplified by military machinery or industrial processes that contribute to environmental degradation.

Over the past decade, there has been a gradual integration of engineering education into school curricula, aimed at fostering students' comprehension of engineering design and practice. The publication of the Next Generation Science Standards (NGSS) in the United States in 2013 marked a significant milestone, amplifying references to engineering practices within STEM education discourse (e.g., Kelly & Green, 2018). Nevertheless, despite engineering's longstanding societal relevance, its introduction into school settings has been relatively recent, prompting questions about its delayed inclusion. The incorporation of engineering topics into curricula has been guided by experts from diverse disciplinary backgrounds and epistemological perspectives, resulting in divergent pedagogical approaches (e.g., Daugherty & Carter, 2018; Purzer et al., 2022; Violante & Vezzetti, 2017). These disparities give rise to significant questions such as: Should engineering education be treated as a distinct discipline or integrated into the science curriculum? Are engineering degrees essential for teachers? Can science educators be trained to teach engineering effectively, and if so, how? These questions remain unresolved, reflecting a scarcity of scholarship on a fundamental question: "What constitutes the nature of engineering?" In this chapter, we endeavor to address this pivotal question by exploring the cognitive and epistemic foundations of engineering as a broad domain, alongside the distinctive attributes of various engineering sub-disciplines.

The Nature of Engineering (NOE)

Over the past two decades, various reports have outlined standards for engineering and technology education, reflecting a concerted effort to integrate these disciplines into educational frameworks (e.g., ITEA, 2007; NAGB, 2018; NGSS Lead States, 2013; NRC, 2009). Notably, the Standards for Technological Literacy (STL) underscored the importance of engineering design by delineating key elements for student engagement (ITEA, 2007). These standards advocate for students to apply a systematic design process to address problems both within and beyond the classroom, emphasizing criteria specification, constraint identification, prototyping, testing, evaluation, and documentation (ITEA, 2007).

Similarly, the Next Generation Science Standards (NGSS) advocate for the integration of engineering concepts and practices to enrich students' understanding of and interest in science (NGSS Lead States, 2013). These standards prompt students to define problem criteria and constraints, evaluate competing solutions, analyze data to inform optimal designs, and develop models of proposed objects, tools, or processes (NGSS Lead States, 2013). The National Assessment Governing Board (NAGB, 2018) has also contributed to the discourse by presenting education standards that encompass technology and engineering literacy. These standards encompass a spectrum of competencies, including systems thinking, maintenance, troubleshooting, idea exchange, solution construction, information research, and more.

Central to these standards is the recognition of the engineering design process and its interconnectedness with science and mathematics education. Consequently, research endeavors have explored students' engagement with design practices through diverse pedagogical approaches. For instance, Mehalik et al. (2008) facilitated student involvement in constructing electrical alarm systems using authentic engineering design practices, revealing greater understanding and knowledge retention, particularly among low-achieving students. Similarly, Berland (2013) investigated the translation of science lessons into engineering contexts, exploring the associated challenges and offering insights for curriculum development.

Building upon these foundations, Cunningham et al. (2020) introduced the 'Engineering is Elementary' program, aiming to integrate engineering and science practices, resulting in significant gains in students' understanding of engineering, technology, and science concepts. Furthermore, interdisciplinary pedagogical approaches advocated by Daugherty and Carter (2018) underscore the interconnectedness of science, technology, engineering, and mathematics (STEM), fostering problem-solving skills and cooperative learning. Recent studies, such as that by Purzer et al. (2022) have advanced frameworks like the honeycomb of engineering, illustrating the versatility of design methodology across multiple domains. This highlights the nuanced goals of engineering education while cautioning against a monolithic definition of engineering (Purzer et al., 2022).

Despite the emphasis on engineering practices within national standards and the promising outcomes showcased in contemporary studies (e.g., Cunningham et al., 2020; Daugherty & Carter, 2018; Purzer et al., 2022), the integration of engineering concepts remains limited in science, technology, and mathematics curricula, with sporadic implementation in classrooms (Carr et al., 2012; Ekiz-Kiran & Aydin-Gunbatar, 2021). To this day, many students complete K-12 education with little or no exposure to engineering education (Hammack & Ivey, 2017; Pleasants & Olson 2019; Purzer, et al., 2022). Several factors contribute to this phenomenon. Firstly, there is a dearth of schoolteachers with an engineering background, as individuals with engineering degrees seldom pursue careers in teaching (Bybee, 2014; Purzer et al., 2022). Consequently, educators lacking proper engineering education may struggle to meet the demands of teaching this subject effectively (Hammack & Ivey, 2017; Purzer et al., 2022). Secondly, there is a limited number of engineering education training programs for both in-service and pre-service teachers, who often possess limited knowledge of design-based practices (Ekiz-Kiran & Aydin-Gunbatar, 2021; NASEM, 2020; NRC, 2009). Lastly, the multifaceted nature of engineering, necessitating the application of advanced science and mathematics, complicates instructional approaches (Barak & Usher, 2022; Honey et al., 2014; Pleasants et al., 2019).

Integration of NOE Into the Science Curriculum

The scarcity of schoolteachers with engineering backgrounds, coupled with an already densely packed curriculum, has necessitated the integration of engineering topics into existing science courses (Ekiz-Kiran & Aydin-Gunbatar, 2021; Johnston et al., 2019). Advocates of this integrative and interdisciplinary approach, such as Brown et al. (2012) and the National Research Council (NRC, 2012), argue that it enriches science education by grounding it in real-world applications (Barak, 2017; Honey et al., 2014; Park et al., 2020). However, without adequate preparation, science teachers may hold misconceptions about the engineering discipline, leading to superficial instruction and limited student learning (Honey et al., 2014; NASEM, 2020; Pleasants & Olson, 2019). Given that most science teachers possess degrees in the sciences, concerns have been raised regarding their lack of engineering background and understanding (Bybee, 2014; Purzer et al., 2022).

Of particular concern is science teachers' ability to distinguish between scientific inquiry and engineering design (Bybee, 2014; Mangiante & Gabriele-Black, 2020). While scientific inquiry seeks to understand natural phenomena by asking questions and testing hypotheses, engineering design aims to solve problems by creating and optimizing practical solutions. Hammack and Ivey (2017) found that many science teachers reported minimal experience in engineering education and struggled to differentiate between engineering and science activities. Other studies have revealed that science teachers, in general, possess limited familiarity with engineering concepts and often hold stereotypical misconceptions about the work of engineers (Cunningham et al., 2006; Purzer et al., 2022). Teachers were found to have limited awareness of the significance of engineering activities and a partial understanding of how to tackle engineering problems. Some erroneously perceived engineers as manual workers in fields like auto mechanics or construction (Hammack & Ivey, 2017; Pleasants & Olson, 2019). For instance, Cunningham et al. (2006) found that teachers were more inclined to view engineers as individuals involved in building construction rather than those overseeing the construction process. Overall, the literature suggests that science teachers' perceptions of engineering and engineering design often do not align with the practices and core ideas outlined in reports such as those by the NRC (2009) or the NGSS Lead States (2013). Given that teachers' conceptions (or misconceptions) can significantly impact students' learning outcomes, there is an increasing need for teacher development programs in engineering education (AE3 & ASEE, 2020; Deniz et al., 2020; Hammack & Ivey, 2017).

Numerous educational studies have proposed pedagogical frameworks for engineering education in schools. Moore et al. (2014) suggested a framework aimed at informing the structure of STEM education standards and initiatives. This framework, focused on quality K–12 engineering education, encompasses twelve key indicators, including 'processes of design' and 'teamwork.' Although distinctions are made between these indicators, there is notable overlap in their application (Moore et al., 2014). Another example is the P–12 engineering learning framework (AE3 & ASEE, 2020), developed to identify learning objectives for engineering literacy. This framework presents a taxonomy of engineering contents derived from a modified Delphi study but places minimal emphasis on connections to science education curricula (AE3 & ASEE, 2020). A more recent framework, the honeycomb of engineering framework, offers a philosophical perspective on pre-college engineering education (Purzer et al., 2022). Categorizing the diverse goals of engineering, this framework emphasizes the centrality of 'design' across various disciplines. However, while the framework can inform lesson design, it does not prescribe effective teaching methods and does not explicitly prioritize teaching the NOE as a learning objective.

To address the scarcity of engineering education programs for science teachers, the National Academies of Sciences, Engineering, and Medicine (NASEM) report

(2020) suggests fostering collaborative dialogues among experts from colleges of education, colleges of engineering, and other stakeholders. The report emphasizes the need for teacher education programs to identify and implement actions that highlight the engineering components within the vision for school science education (NASEM, 2020). Such programs should support the development of deep pedagogical content knowledge in engineering to prevent the conflation and confusion of science and engineering (Antink-Meyer & Brown, 2019; Johnston et al., 2019; NASEM, 2020). Authentic representations of science and engineering in classrooms necessitate a well-developed understanding of the nature of science and the nature of engineering (Erduran, 2020; Pleasants et al., 2019). Accordingly, the NASEM (2020) report underscores the importance of illuminating the essential qualities of engineering, the design process, and core engineering concepts. It calls for a nuanced conceptualization of 'engineering' and its distinction from 'science' and 'technology,' themes further explored in the subsequent section.

Distinguishing Engineering from Science and Technology

While science, technology, and engineering are interconnected, they possess distinct cognitive and epistemic characteristics that necessitate clear definitions and differentiations (Antink-Meyer & Brown, 2019; McComas & Burgin, 2020; NASEM, 2020). When engineering design tasks are introduced in science classrooms, the boundaries between these disciplines can become blurred, resulting in conflation (Johnston et al., 2019; NASEM, 2020). Given their interdependence, it is crucial to carefully examine the relationships among science, engineering, and technology within the context of school education.

The distinction between science and engineering or technology is relatively clear. Science entails a systematic exploration of the natural and physical world through methods such as observation, experimentation, modeling, and classification (NSTA & ASTE, 2019; NGSS Lead States, 2013). It seeks to answer questions about the natural world, while engineering and technology focus on designing and developing human-made artifacts. Distinguishing between engineering and technology presents a greater challenge, as they are often used interchangeably to describe aspects of human-developed products. Nonetheless, understanding each discipline's theoretical and practical aspects is essential for their integration into the science curriculum (NAGB, 2018; NASEM, 2020).

According to the National Assessment Governing Board (2018), engineering is defined as "a systematic and often iterative approach to designing objects, processes, and systems to meet human needs and wants" (NAGB, 2018, p. 5), while technology encompasses "products, processes, and systems created by people to meet human needs and desires" (NAGB, 2018, p. 23). Pleasants and

Olson (2019) assert that engineers work with nature and its laws, as revealed by science, focusing on creative problem-solving processes involving testing and revisions. In contrast, technologists emphasize the construction aspect, viewing technology as both the means to solve problems and the end product. In summary, the connections and distinctions among the three disciplines can be encapsulated as follows: Guided by scientific principles, engineering involves the knowledge and practices necessary for designing new or improved technologies (NAGB, 2018; NASEM, 2020). With appropriate support and guidance, science teachers with limited formal engineering education can develop an understanding of engineering (e.g., Deniz et al., 2020; Pleasants & Olson, 2019). This underscores the importance of developing a conceptual framework of the nature of engineering from both cognitive and epistemic perspectives (Pleasants & Olson, 2019; Purzer et al., 2022). Consequently, it is imperative to highlight the key aspects of various engineering fields.

Domains Within Engineering

While engineering education within the context of science education is gaining momentum, engineering is often presented broadly without adequate differentiation across its various sub-fields (Purzer et al., 2022). To understand the nuances of engineering, it is essential to distinguish between its different aspects and fields. Engineering, fundamentally, focuses on designing and creating new or improved artifacts—a term derived from Latin meaning "by skill" and "to make." These artifacts encompass not only tangible machinery and tools but also intangible entities like computer software, design documents, written patents, and even subcellular nanorobots. Over time, engineering has evolved into distinct fields and sub-fields, each with its area of specialization. Some of these include civil, environmental, chemical, mechanical, computer, aerospace, and more (ABET, 2019; ITEA, 2007; NASEM, 2020). Based on the created artifacts, engineering can be broadly categorized into four main categories: Structures, Machines, Materials, and Data.

Structures engineering focuses on planning and constructing buildings and infrastructures to meet human needs and address societal challenges (ABET, 2019; NASEM, 2020). Dating back to ancient times with the construction of pyramids and aqueducts, civil and architectural engineering disciplines are typically involved in this area.

Machines engineering deals with the development of complex devices and tools assembled from mechanical parts to perform specific tasks. It spans various transmission methods such as mechanical, electrical, hydraulic, and pneumatic, and is prominent in mechanical, biomedical, aerospace, and naval engineering (ABET, 2019; ITEA, 2007).

Materials engineering involves the manipulation of materials—solids, liquids, gases, and other condensed phases—to develop useful products. This includes everything from chemical processes to the manufacturing of polymers, ceramics, metals, and advanced materials like semiconductors and nanomaterials (ITEA, 2007; NASEM, 2020).

Data engineering encompasses the development and use of computer-based data, involving creating and manipulating electrical signals to process and store information. It focuses on data analysis, design techniques, and the synthesis of digital signals, playing a crucial role in computer, electrical, and systems engineering (ABET, 2019; ITEA, 2007).

Despite the growing interest in engineering education, existing frameworks often lack a holistic conceptualization of the nature of engineering. While educational frameworks provide pedagogical components and indicators, they fall short in fully defining and instructing the NOE, which is essential for developing engineering literacy (Antink-Meyer & Arias, 2022; Pleasants & Olson, 2019). Defining and teaching the NOE remains a challenge for educational systems worldwide (Antink-Meyer & Arias, 2022; NASEM, 2020), emphasizing the need for comprehensive frameworks and reliable tools for instruction and assessment. Additionally, while there is recognition of the pedagogical benefits of engineering learning, less attention has been given to the cognitive and epistemic aspects of engineering practices (Purzer et al., 2022). Drawing upon previous studies, this paper utilizes the Family Resemblance Approach (FRA) as a methodological framework to analyze and develop the NOE framework (Erduran et al., 2019; Irzik & Nola, 2011; Kaya & Erduran, 2016).

The NOE from the perspective of the Family Resemblance Approach

Emerging research suggests that the FRA offers a promising framework for cultivating an inclusive understanding of both the cognitive-epistemic and social-institutional dimensions of NOE (Barak et al., 2024; Aydın-Günbatar & Roehrig, 2023). This is based on the literature that presents the FRA as a framework for holistic and nuanced conceptualization of the nature of science (NOS) (Erduran & Kaya, 2018; 2019). In this study, the FRA was utilized for its unique capacity to incorporate domain-general and domain-specific features, making it particularly useful for examining how science and engineering education is conceptualized and understood (Barak et al., 2024; Erduran & Kaya, 2018; 2019; Park, Wu, & Erduran, 2020).

Drawing from recommendations made by the literature (e.g., Barak, 2023; Cheung & Erduran, 2023; Erduran et al., 2021; Okan & Kaya, 2023; Park & Brock, 2023; Reinisch & Fricke, 2022), we situated each FRA category within the context of educational studies and policy reports, such as NGSS Lead states (2013), the National Academies of Sciences, Engineering, and Medicine (NASEM, 2020), and the National Assessment Governing Board (NAGB, 2018). Due to space limitations, the following sections provide selected examples of educational applications.

Aims & values: Engineers, similar to scientists, are guided by aims and values such as precision, reasoning, logic, and creativity (AE3 & ASEE, 2020; NASEM, 2020). Table 1 shows different perspectives of the aims and values of science and engineering education with examples of educational applications.

Table 1. Aims and values of science and engineering education.

Aims and values	Science applications (from Erduran & Dagher, 2014)	Engineering applications
Objectivity	Seeking neutrality and avoiding bias.	Evaluating design alternatives, emphasizing objectivity with a clear and rational mindset.
Novelty	Searching for new explanations.	Creating new and innovative solutions to complex challenges through creative thinking and critical evaluation.
Accuracy	Ensuring that explanations are accurate.	Ensuring that designs, measurements, and calculations are reliable and free from errors.
Critical examination	Giving reasons to justify claims.	Evaluating the designs, processes, and solutions through systematic analysis, questioning assumptions, testing hypotheses, and scrutinizing the validity of solutions.
Addressing anomalies	Recognizing opposite ideas and responding to objections	Systematically evaluating the feasibility, effectiveness, and trade-offs to recognize the most promising solution.

Practices: Engineering practices are described in the Framework for K-12 Science Education (NGSS Lead States, 2013) and other policy reports (e.g., NAGB, 2018; AE3 & ASEE, 2020). Accordingly, engineering practices involve a complex process of defining human-related problems, developing and using engineering models, and designing solutions, as detailed by the Practices part of the NGSS Framework (2013): P1. Defining human-related problems; P2. Developing and using (engineering) models; P3. Planning and carrying out investigations; P4.

Analyzing and interpreting (engineering) data; P5. Using mathematics and computational thinking; P6. Designing solutions; P7. Engaging in argument from evidence; P8. Obtaining, evaluating, and communicating information. These practices require a meta-level of understanding, which aligns with the FRA framework. Adapting the scientific heuristics (Erduran & Dagher, 2014; Erduran et al., 2021) to engineering practices, Figure 1. shows a holistic representation of the engineering practices with their corresponding heuristic features and examples for learning assignments. P7 and P8 are integral to and interacting with the other six engineering practices, and therefore are in the middle of the model. The engineering Production feature, which replaces the Prediction feature within the scientific practices (Erduran & Dagher, 2014) is not mentioned explicitly as part of the Practices (NGSS Lead States, 2013). It is therefore denoted as Px in the model.

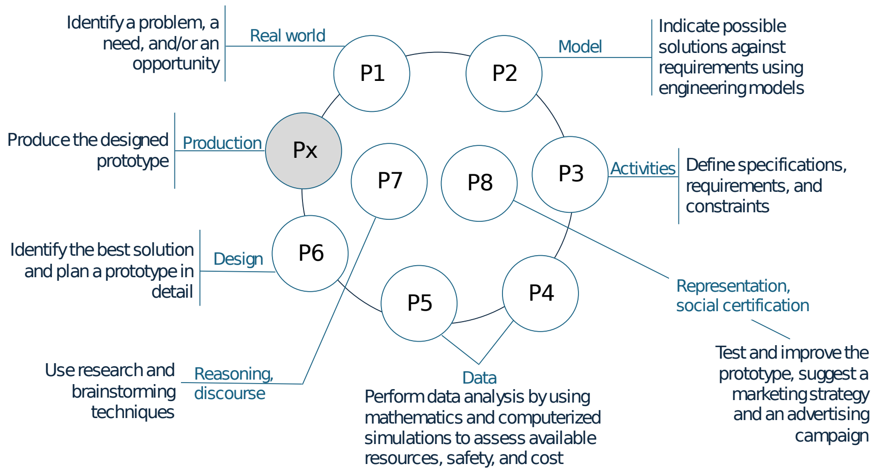

Fig. 1. Engineering practices, heuristic features, and example learning assignments.

Methods & methodological rules: Methods and methodological rules in engineering encompass a diverse range of systematic guidelines and approaches employed to guarantee that investigative outcomes yield accurate and reliable knowledge (Erduran & Dagher, 2014; Irzik & Nola, 2011). Epistemic ideas relevant to engineering education may include design methods (DM's) grouped into four types of artifacts (4 A's): Materials, Machines, Structures, and Data (Figure 2). In fields such as chemical engineering (*Materials*) and mechanical engineering (*Machines*), Biomimicry emerges as a prominent engineering design approach. Rooted in the emulation of natural materials, mechanisms, and processes, Biomimicry offers innovative solutions to human design challenges. For example, the biomechanics of the gecko lizard's toes have inspired a host of climbing materials, and the hydrodynamics of the whales' swimming has inspired the design of submarines. In fields such as architecture and urban planning (*Structures*), the *Mixed-Use Design* is employed, uniting three or more functions within a single structure, including transportation, residential, hotel, retail, entertainment, and parking. This design method prioritizes the preservation of quality of life while mitigating environmental impact. Other design methods include the *Design for Assembly* and the *Reverse Engineering* method. These four design methods were chosen because they represent a diverse spectrum of systematic approaches that address different aspects of engineering problem-solving. These methods transcend specific disciplines and are adaptable to different contexts, ensuring solutions are accurate and reliable. Of course, these are not the only design methods available, and other approaches may be equally valuable depending on the context and objectives of the project at hand. Regardless of the engineering methods chosen, they - like scientific methods - should be practiced in schools as a creative process involving more than one approach.

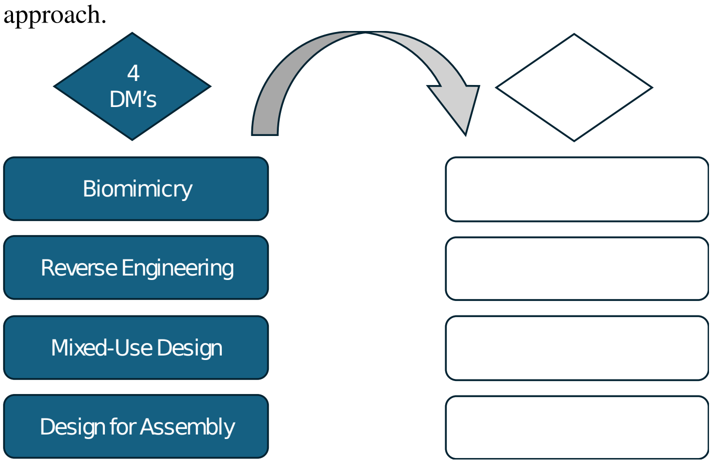

Fig. 2. The four design methods (4 DM's), grouped into four types of artifacts (4 A's).

Engineering knowledge: While scientific knowledge is typically considered the 'end-product' of scientific endeavors (Erduran & Dagher, 2014; Irzik & Nola, 2011), engineering knowledge emerges from the processes of design and manufacturing (NAGB, 2018; NASEM, 2020). This type of knowledge pertains to the functioning of artifacts and the application of analytical models across various technologies (Pleasants & Olson, 2019). When examining the disciplinary aspects of engineering for K-12 education, scholars inquire into engineering knowledge by posing questions such as: What types of knowledge are inherent to the engineering discipline? How does engineering science differ from and resemble natural science? And to what extent do models of the design process accurately depict designers' actual work? (Pleasants & Olson, 2019). Building upon this foundation, the literature delineates various facets of the nature of engineering knowledge crucial for K-12 educators with limited engineering backgrounds, encompassing empirical, contextually responsive, social, personal, societal and cultural, interdisciplinary, and solution-oriented dimensions (Antink-Meyer & Brown, 2019). Beyond mere content knowledge, engineering knowledge comprises a fusion of scientific and mathematical theories, laws, and models that underpin all engineering practices (NAGB, 2018). It encompasses the practical applications of the engineering enterprise, validating and generating engineering concepts. Providing logical and systematic explanations of the workings of human-made artifacts, engineering knowledge fosters innovation and continued development (Barak et al., 2024).

Discussion

In recent years, the importance of engineering literacy in navigating a technology-driven society has garnered significant attention, leading to discussions about pre-college engineering education in policy reports and academic studies (AE3 & ASEE, 2020; Antink-Meyer & Brown, 2019; English & Moore, 2018). However, despite this growing recognition, teaching the NOE remains in its nascent stages (Aydın-Günbatar & Roehrig, 2023; Barak et al., 2024). The literature underscores the necessity of conceptualizing and integrating NOE into the science curriculum (Antink-Meyer & Arias, 2022; Deniz et al., 2020; Parrish et al., 2024; Pleasants & Olson, 2019). Drawing parallels with the deeper understanding fostered by exploring the NOS (e.g., Antink-Meyer & Brown, 2019; Barak et al., 2023; Erduran et al., 2019; Lederman, 1992; Okan & Kaya, 2023), there is a clear imperative to establish an ontological and pedagogical framework for engineering that delves into the cognitive and epistemic approaches utilized by engineers across various domains.

This chapter contributes a novel perspective to the ongoing discourse surrounding NOE heuristics and applications by likening it to the conceptualization of NOS. Theorizing NOE presents inherent complexities, as engineering is perceived as both a process, a discipline, and an approach (Antink-Meyer & Brown, 2019). Moreover, delineating the cognitive and epistemic characteristics that both differentiate and unite engineering and science poses significant challenges (Antink-Meyer & Brown, 2019; McComas & Burgin, 2020; NASEM, 2020). Nevertheless, advancing the theoretical understanding of NOE is paramount for fostering scientific and engineering literacies, as integrated teaching can deepen the understanding of modern society (Antink-Meyer & Arias, 2022; Pleasants & Olson, 2019).

Building upon the family resemblance approach (FRA) as framed by Erduran and Dagher (2014), this chapter explains NOE through four cognitive and epistemic categories: Aims & Values, Engineering Practices, Methods & Methodological Rules, and Engineering Knowledge. Leveraging the FRA as a methodological lens can inform the teaching and learning of engineering in educational settings. In teacher development programs, this approach can facilitate the introduction of the multifaceted NOE and aid educators in selecting and delivering NOE-related learning activities aligned with educational objectives. The four discussed FRA cognitive-epistemic categories furnish a comprehensive and cohesive conceptualization of NOE, fostering a shared understanding of the engineering enterprise among educational stakeholders. This cognitive-epistemic dimension of NOE is pivotal for cultivating a unified, holistic comprehension of engineering and its theoretical and practical interplay with science, thereby providing a framework for the development of engineering education in schools.

With the aim of promoting engineering literacy as a guiding principle, future research endeavors should explore additional dimensions of the NOE, aiming to construct a comprehensive conceptualization within the framework of school science education. This study suggests that the FRA may provide a comprehensive, holistic approach to the NOE, allowing for a nuanced understanding of it. Building upon this conceptualization, future research should utilize empirical data to examine the understanding of the NOE using the FRA as a guiding framework. The FRA categories could serve as both theoretical and methodological lenses for identifying gaps in the understanding of NOE and for offering heuristics to enhance this understanding. There is a pressing need to identify further heuristics that contribute to the formation of NOE understanding and facilitate its seamless integration into the science curriculum. By delving deeper into these aspects, researchers can enrich our understanding of engineering education and pave the way for more effective pedagogical strategies in fostering engineering literacy among students.

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