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ARTICLE

Rethinking the Nature of Engineering: Attending to the Social Context of Engineering

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Abstract

As part of a growing emphasis on "STEM," engineering has gained prominence in precollege education. In response to that trend, an emerging area of educational research focuses on the "Nature of Engineering" (NOE), a collection of ideas about what engineering is, what engineers do, and how engineering is related to science and society. In recent years, multiple NOE frameworks have been developed, along with associated NOE instruments. Thus far, NOE research has often taken cues and utilized concepts from the extensive body of nature of science literature. While there is much to be gained from nature of science research, in this paper I raise concerns with using the nature of science as a template for the NOE. I examine several NOE frameworks and identify issues and gaps that arise from the application of nature of science-based approaches. That analysis indicates that extant NOE frameworks overlook the professional contexts in which engineering work occurs, and the ways that those contexts cause engineering practice to differ from that of science. Attending to and understanding the professional context of engineering is essential for describing the sociocultural dimensions of the NOE, which are of primary importance when it comes to engineering literacy. In addition to clarifying the NOE, I offer suggestions for how giving more attention to these NOE dimensions can move this field of research, and precollege engineering instruction, forward.

Keywords Nature of Engineering · Nature of Science · Engineering Literacy · Engineering Education

In the past decade, increasing emphasis has been placed on engineering within pre-college education, particularly as part of the growing focus on STEM education in the United States and around the world (Carr et al., 2012; Cunningham & Carlsen, 2014; Martín-Páez et al., 2019; National Research Council, 2012; Park et al., 2020; Ritz & Fan, 2015). Among ongoing conversations around what pre-college engineering education should include, an area of growing interest is the place of the Nature of Engineering (NOE) within STEM instruction. Like the nature of science, the NOE is a collection of related concepts regarding what engineering is, how engineering work is conducted, the place of engineering in

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society, and the relationships between engineering and related fields such as science (Pleasants & Olson, 2019). Just as the nature of science is considered an essential part of scientific literacy (Lederman & Lederman, 2014; McComas & Clough, 2020; Zeidler et al., 2013), understanding the NOE is argued to be an important component of engineering literacy (Antink-Meyer & Brown, 2019; International Technology and Engineering Education Association [ITEEA], 2020; National Academy of Engineering & National Research Council [NAE & NRC], 2009; Pleasants & Olson, 2019). It is also considered useful for teachers, as understanding the NOE can help them create more authentic engineering experiences for students (Antink-Meyer & Arias, 2022; Barak et al., 2022; Deniz et al., 2020; National Academies of Science, Engineering, and Medicine [NASEM], 2020; Parrish et al., 2022; Pleasants, 2021; Pleasants et al., 2020).

In recent years, multiple education researchers have sought to describe and clarify various dimensions of the NOE (e.g., Antink-Meyer & Brown, 2019; Barak et al., 2022; Deniz et al., 2020; Hartman, 2016; Karatas et al., 2011; Pleasants & Olson, 2019). In broad terms, those frameworks offer similar overall accounts of the NOE, although differences can be found in their details, areas of emphasis, and conceptual categories. Based on those various frameworks, NOE instruments have been developed (e.g., Antink-Meyer & Brown, 2020; Kaya, 2020; Kaya et al., 2023; Parrish et al., 2022; Pleasants, 2021) and no doubt more are on the way. My goal in this paper is not to add to this growing collection, but instead to identify some unnoticed and unresolved issues within these lines of research.

Much of the research on the NOE has leveraged ideas from the extensive literature regarding the nature of science in science education. This is not to say that the fields of science and engineering have been conflated; indeed, much of the work around the NOE has drawn distinctions between the two (e.g., Antink-Meyer & Brown, 2019; Barak et al., 2022; McComas & Burgin, 2020; Pleasants, 2020; Pleasants et al., 2023). However, there is an assumption that the NOE can be approached using similar approaches and conceptual schemas as those used for nature of science. In this paper, I examine ways in which that assumption has led to issues and omissions in extant NOE conceptualizations. Specifically, I argue that using the nature of science as a template for the NOE has caused important aspects of the social context of professional engineering work to be overlooked. Professional engineering is organized in ways that are very different from that of science, and this fact has substantial implications for how engineering is done and its relationship with society. Giving greater attention to this dimension of the NOE adds clarity and depth to the social aspects of engineering, including the ways that engineering intersects with sociocultural values. These ideas are not just minor details, but ones that are essential components of engineering literacy.

1 Using the Nature of Science to Approach the NOE: Some Concerns

One of my central claims is that using the nature of science as a template for framing and describing the NOE is a limited approach. To make that case, I will begin with a close examination of a recently published framework put forth by Barak et al. (2022). They sought to describe the "cognitive and epistemic underpinnings of engineering as a broad domain" (p. 2) by applying the Family Resemblance Approach (FRA) that Erduran and Dagher (2014) developed to conceptualize the nature of science. Barak et al. (2022) are not the only ones to utilize nature of science approaches, but their work serves as a useful starting point because it is both a recent entry in the NOE literature and it exemplifies the application of nature of science categories to engineering. After examining their framework and identifying some concerns, I will address similar issues with nature of science-based approaches in other existing NOE frameworks.

Barak et al. (2022) are the first to specifically apply Erduran and Dagher's (2014) FRA framework to engineering. A family resemblances view, in the fashion of Wittgenstein (1953) or Pigliucci (2013), is a logical way to approach engineering given the diversity of engineering specializations (Pleasants, 2021). We would expect differences to exist between, for instance, the natures of chemical engineering, industrial engineering, and structural engineering. Yet while thinking about engineering in terms of family resemblances is worthwhile, it is worth interrogating the extent to which the conceptual categories of Erduran and Dagher's (2014) FRA framework are applicable to engineering. Barak et al. (2022) approach the NOE via the FRA categories, focusing on four categories within the "cognitive and epistemic" domain of the FRA framework: Aims & Values, Practices, Methods & Methodological Rules, and Knowledge. The Aims & Values category is of particular interest here, as prior researchers argue that it is along those dimensions that engineering can most clearly be distinguished from science (McComas & Burgin, 2020; Pleasants, 2020; Pleasants et al., 2023). Barak et al. (2022) acknowledge that the aims and values of science and engineering differ, but nevertheless use the following nature of science categories to describe the NOE:

> (a) objectivity—seeking neutrality and avoiding bias, (b) novelty—searching for new explanations, (c) accuracy—ensuring that explanations are accurate, (d) empirical adequacy—basing claims on relevant and plausible data, (e) critical examination—giving reasons to justify claims, (f) addressing anomalies—recognizing opposite ideas and responding to objections, and (g) taking challenges—addressing opposition to own ideas seriously. (p. 9)

Barak et al. (2022) adapt those categories by accounting for the fact that engineering creates technologies whereas science produces knowledge of the natural world. However, those categories prove to be not so flexible. Take, for example, the adaptation of "Addressing Anomalies" for engineering:

> *Addressing anomalies* refers to choosing the most suitable solution within limitations imposed by resources, technology, safety, and cost, providing reliable and robust solutions to an engineering problem. (p. 10)

In transporting this concept to the field of engineering, the scientific sense of "anomalies" (cf. Kuhn, 1962/1970; Popper, 1963/2002) has been lost. It also introduces new values that differ from those of science, including the pursuit of safety, low cost, reliability, practicality, and efficiency. A similar phenomenon occurs when translating "Taking Challenges Seriously:"

> "*Taking challenges seriously* refers to addressing financial, environmental, social, and ethical constraints to generate sustainable engineering outcomes" (p. 10)

The concern here is that what began as a set of epistemic values for science now has a very different character. The original meanings of the conceptual categories have faded and different values (e.g., efficiency, practicality, ethics, sustainability) have been introduced. Worth noting is that some of those values, especially sustainability and ethics, are ones that are contested among engineering scholars (Bucciarelli, 2008; Cech, 2014; Conlon, 2008; Harris, 2013; Herkert, 2001; Johnston et al., 1996; Mitcham, 2009). I raise these issues, though, not to "set the record straight" regarding the epistemic aims and values of engineering. Rather, my point is that conceptual categories used to describe the nature of science are not necessarily appropriate for the NOE. At a broad level, using "Aims and

Values" as a component of the NOE might have merit. But as my analysis of Barak et al. (2022) suggests, the specific concepts and constructs might also prove to be a procrustean bed. In the following section, I further explain and explore why this is the case.

2 The Need for a Different Approach

We can describe the aims and values of science because a scientific community exists that, while composed of individuals who are situated in a wide range of settings and locations, works together in a collective knowledge-building enterprise (Erduran & Dagher, 2014; Irzik & Nola, 2014; Oreskes, 2019). The boundaries of that community can be murky, porous, and contested, but there is nevertheless a sense in which science is a collective project with a commonly-held set of goals, norms, and values. The community is maintained in a variety of ways, including the dissemination channels through which scientists share, scrutinize, critique, and build upon each other's work (Erduran & Dagher, 2014; McIntyre, 2019; Oreskes, 2019). Even if the actual practice of scientists involves a far more complex assortment of practices, priorities, and values (Latour & Woolgar, 1979), there is nevertheless good reason to articulate the features of science-as-collective-practice.

Perhaps engineering can also be thought of as a collective knowledge-building project, with the caveat that it is oriented toward technological knowledge rather than knowledge of the natural world. Indeed, academic engineering – research work conducted at universities – has mostly patterned itself after science and could be conceptualized as a collective knowledge-building endeavor (Bucciarelli, 2009; Houkes, 2009). However, most engineering is done in a professional, not academic, context (NSB, 2020). Those professional contexts include private companies (e.g., Intel, General Electric, a technology startup), engineering firms that consult and contract with various industry clients, and the public sector (e.g., city governments, public utilities). The characteristics of engineering in those contexts is quite distinct from academic engineering and is not necessarily akin to science. Scientists, of course, also work in a variety of settings, from institutions of higher education to dedicated research laboratories. Discussions of the nature of science acknowledge that those contexts influence scientific research (see Erduran & Dagher, 2014, p. 145–146; Wible, 1997), but they are generally regarded as ancillary to the *collective* project of science. An exception that serves to reinforce this point is the case of individuals with scientific training who work in private industries (often for the purpose of technological development). When they do so, they take a step away from the scientific community. While the connections are not wholly severed, it is generally assumed that the work of scientists within private companies has a different character. When researchers from private industry do share their work with the wider community, it is justifiably subjected to intense scrutiny (McIntyre, 2019; Oreskes, 2019). When we speak of the nature of science, then, we usually are not describing what is done by scientists who work in private companies.

Unlike the case for the nature of science, the professional work context of engineering ought not to be treated as an incidental feature of the NOE. As scholars of engineering have argued (e.g., Conlon & Zandvoort, 2011; Lynch & Kline, 2000; Trevelyan, 2010), engineering needs to be described in ways that recognize how it is practiced in society rather than in abstract terms. The fact that engineering predominantly occurs in professional rather than academic contexts has many implications for the NOE. The problems that engineers address and the design goals that they pursue are much more strongly determined by their employers and clients than they are by a wider professional community (Conlon &

Zandvoort, 2011; Conlon, 2008; Johnston et al., 1996; Lynch & Kline, 2000; Meiksins & Smith, 1996; Mitcham, 2009). In fact, for engineers in the private sector, contributing to a wider community is likely to be actively discouraged if not outright prohibited by their employers to safeguard intellectual property (Stjepandić et al., 2015). Local communities of engineers may form *within* organizations, but engineers are only loosely connected between and across organizations (Bucciarelli, 1996). Figure 1 provides an image of this professional structure. Engineers are embedded in professional work settings alongside non-engineers, and are only loosely tied to the work of engineers across those settings.

Recognizing the importance of the context of professional engineering work does not necessarily mean that engineers are completely disconnected from one another. There are similarities to be found across professional contexts (Anderson et al., 2010; Trevelyan, 2010) and there are similar ways of thinking and acting that connect engineers (Cross, 2006; Dym et al., 2005; Dym & Brown, 2012; Pleasants & Olson, 2019; Stevens et al., 2014). The process of educating engineers is often viewed as one of enculturating students into a set of shared approaches and ways of thinking that are reflective of the broader engineering community (Cech, 2014, 2015; Lakin et al., 2020; Trevelyan, 2019). Engineers across different contexts are also connected to one another via professional engineering organizations. Those

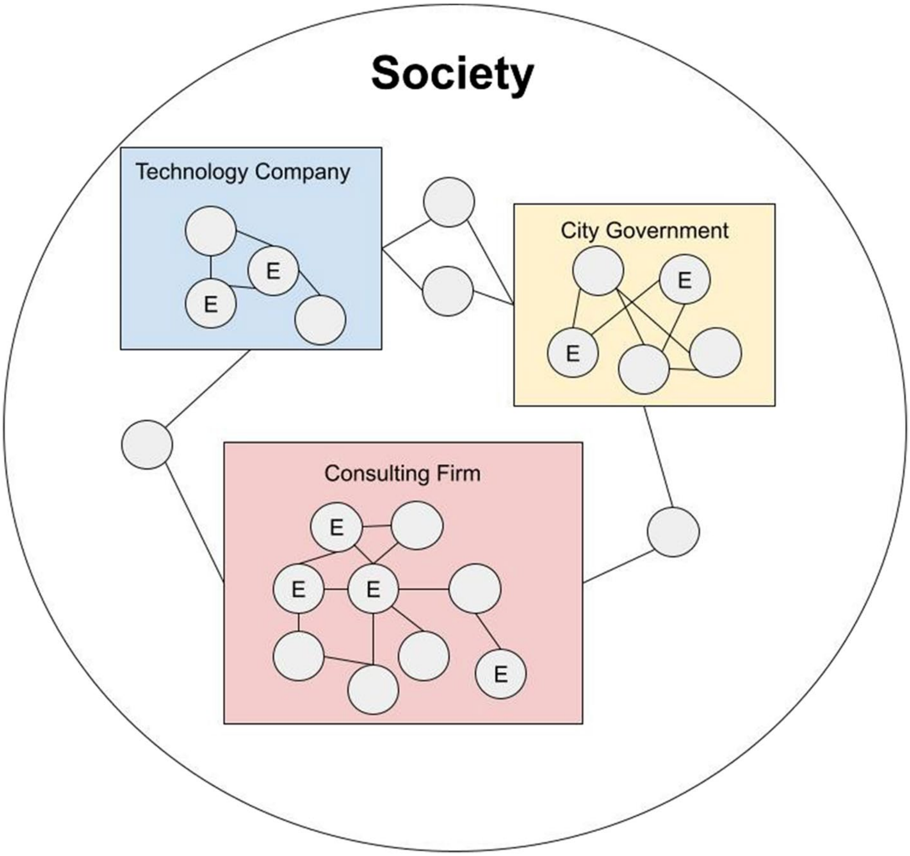

Fig. 1 A model of the professional structure of engineering

organization set standards and regulations that codify how certain technologies are to be constructed (e.g., IEEE 2022) as well as ethical codes (Mitcham, 2009; Tang and Nieusma, 2015). To the extent that we wish to describe engineering as a knowledge-building activity (e.g., Antink-Meyer & Brown, 2019; Cunningham & Kelly, 2017), there are ways in which communal knowledge is shared and built (Houkes, 2009; Vincenti, 1990). Although it is not the dominant work context, academic engineering does create technological knowledge that is widely disseminated. Patents can also be thought of as contributions to engineering knowledge, though refracted through the prism of intellectual property. Though private companies jealously guard their technological knowledge, one way or another it tends to work its way into widespread practice (Vincenti, 1990).

That said, to regard engineering as a collective endeavor (knowledge-producing or otherwise) in the same sense as science is misleading. The professional context in which engineering occurs causes it to deviate from the patterns of science in profound ways. Most importantly, professional engineering work is done *for* local organizations (employers, clients) rather than *for* the broader engineering community (Conlon, 2008; Lynch & Kline, 2000; Meiksins & Smith, 1996). In addition, engineers play just one role among many when it comes to the process of technological development. Technologies are not created solely by engineers, and a great deal of engineering work involves coordinating the activities of various individuals involved in the process of research, design, and development (Law et al., 2012; Mitcham, 1994; Trevelyan, 2007, 2010). While existing descriptions of the NOE do recognize that the products of engineering are context-specific whereas scientific knowledge is context-general (Antink-Meyer & Brown, 2019; Cunningham & Kelly, 2017; Deniz et al., 2020; Pleasants & Olson, 2019), those frameworks give little attention to the *work* contexts of engineers.

At this point, let us return to the question of aims and values of engineering, and the descriptions given by Barak et al. (2022). Applying the specific FRA constructs to engineering assumes that engineering has aims and values as if it were a collective knowledge-building venture akin to science. If we instead understand most engineering work as being concerned with local technological problems, defined by their local contexts of employment, it may not be accurate to speak of aims and values of engineering writ large. Safety, efficiency, reliability, and cost are often qualities of concern for engineering projects, but the extent to which those qualities are pursued depends on the concerns of the employer or client (Bucciarelli, 2008; Conlon, 2008; Lynch & Kline, 2000; Mitcham, 2009). Engineering does not have the equivalent of a scientific peer-review process whereby collectively held values are upheld and reinforced. Goals such as sustainability might be prioritized or largely ignored. Depending on the field, engineers' work *does* need to adhere to established technical standards and regulations (e.g., IEEE, 2022), but those guidelines are typically oriented toward narrow goals of ensuring minimum levels of safety and technical competence (Conlon, 2008; Mitcham, 2009; Trevelyan, 2010). It is a stretch to say that engineering standards are doing the same work as the epistemic aims and values that have been described for science (Erduran & Dagher, 2014; Irzik & Nola, 2011).

Pulling together these threads, my central argument is that approaching the NOE as if it were analogous to the nature of science will result in overlooking how professional engineering is socially organized and practiced. Because science is not organized as a profession (in the way that engineers, doctors, or lawyers are organized), nature of science constructs are inattentive to professional structures, which makes them insufficient tools for conceptualizing and describing the NOE. Instead of trying to fit engineering into our ways of thinking about science, NOE frameworks need to approach engineering on its own terms, as it is practiced in the world (Trevelyan, 2010).

3 Addressing Gaps in NOE Frameworks

The foregoing discussion is not only consequential when trying to describe the NOE in terms of aims and values. Paying attention to the professional context of engineering work is essential for describing the social aspects of engineering. Existing NOE frameworks (e.g., Antink-Meyer & Brown, 2019; Barak et al., 2022; Deniz et al., 2020; Pleasants & Olson, 2019) all include descriptions of the social dimensions of engineering (e.g., how engineering is situated in and influenced by the larger culture). However, as I argue in this section, extant descriptions (and I include my own among them) of those social aspects lack nuance and depth because they have given inadequate attention to the contexts in which professional engineering occurs. Here as well, I argue that the underlying reason for these oversights is that the nature of science has been taken as the starting point for describing the NOE.

Social aspects of engineering have been addressed in NOE frameworks via a "sociocultural embeddedness" dimension. In the analysis that follows, I aim to show the limitations of existing descriptions and point to ways that those limitations can be addressed by paying greater attention to the ways that engineering is professionally structured. I specifically examine descriptions of this dimension within the NOE frameworks of Antink-Meyer and Brown (2019) and Deniz et al. (2020). But as I have indicated elsewhere, my focus on these specific works should be taken as illustrative; they are not the only examples of the problems that I describe. In fact, I freely admit that I have been insufficiently attentive to the social aspects and organizational structures of engineering in my own work (Pleasants & Olson, 2019).

I will begin my examination of this issue with the "Nature of Engineering Knowledge" framework developed by Antink-Meyer and Brown (2019) that centers "characteristics of engineering knowledge" (p. 540), which they explain "includes design within the term *engineering knowledge*" (p. 540, emphasis in original). Their focus on engineering *knowledge* already suggests a desire to pattern the NOE after the nature of science, which has been described as chiefly concerned with the nature of scientific knowledge (Lederman & Lederman, 2014). Antink-Meyer and Brown include a "Societal and Cultural" dimension in their framework, and they begin by stating, "Just as NOS has been described as socioculturally embedded, engineering, as a way of knowing among people, shares this characteristic" (p. 550). They point out that the connections between engineering and society are widely acknowledged because the products of engineering have obvious social effects, and they cite genetically modified crops as an example. Drawing heavily from language in the *Framework for K-12 Science Education* (NRC, 2012), they provide a more detailed description of this NOE dimension, from which I will quote at length:

> …engineering knowledge is reflective of social and cultural communities and contexts. Every "proposed solution results from a process of balancing competing criteria of desired functions, technological feasibility, cost, safety, esthetics, and compliance with legal requirements. There is usually no single best solution but rather a range of solutions" (NRC 2012, p. 52). That range is both reflective and affective of society because design solutions are embedded in the issues and desires of communities. This is the case beyond legal requirements compliance… The esthetics to which they appeal are socially and culturally grounded, and their own ideas are reflective of their experiences and sensibilities as members of localized, international, and cultural communities. (p. 550)

Their main point here is that engineering requires value judgments when balancing different criteria. Engineers' value judgments, they argue, are reflective of the communities in which they are embedded. In short, engineers will hold culturally-bound beliefs that will influence their design choices.

In their NOE description, Deniz et al. (2020) put forth a very similar set of ideas. They describe the "Social and Cultural Embeddedness" of engineering as follows:

> Engineering is a human activity. There is a continued interaction between engineering and society. Sociocultural factors influence the engineering design process, and in turn, engineering influences the society. These social and cultural factors include social composition, religion, worldview, political, and economic factors. (p. 5)

Like Antink-Meyer and Brown (2019), the main idea here is that certain values and beliefs of "society at large" will inevitably make their way into engineers' work. Interestingly, the description given by Deniz et al. (2020) mirrors the one presented by Lederman et al. (2002) for the parallel nature of science dimension:

> Science as a human enterprise is practiced in the context of a larger culture and its practitioners are the product of that culture. Science, it follows, affects and is affected by the various elements and intellectual spheres of the culture in which it is embedded. These elements include, but are not limited to, social fabric, power structures, politics, socioeconomic factors, philosophy, and religion. (Lederman et al., 2002, p. 501)

The similarity is intentional; Deniz et al. (2020) present their NOE framework in conjunction with an NOE instrument that is modeled after the VNOS questionnaire (Lederman et al., 2002).

For both Antink-Meyer and Brown (2019) and Deniz et al. (2020), their conceptualizations of the sociocultural aspects of engineering have been significantly informed by the analogous nature of science dimension. The resulting descriptions broadly gesture to the fact that cultural beliefs will inevitably make their way into engineers' thinking and decision-making. This is not an objectionable idea as far as it goes. The idea that engineering requires value judgments, and that those judgements inevitably derive from social and cultural values, is well supported (Kroes, 2012; Van de Poel, 2013; Vincenti, 1990). But what is missing is a sense of *how* values make their way into design choices. The broad references to "communities" and "society" gives the impression that engineers have a main line to the values of the lay public or, perhaps, a group of unnamed "stakeholders." However, when it comes to setting the design parameters for a technology, the most influential community is the organization for which the engineer works (Conlon & Zandvoort, 2011; Conlon, 2008; Johnston et al., 1996; Lynch & Kline, 2000; Meiksins & Smith, 1996; Suchman, 2000). A private company might, but also might not, pursue values and outcomes that align with the communities in which they are situated, or society at large, or even those who use their products. For instance, most users of technologies would prefer that they be able to repair their devices (Jordans, 2021). And yet, John Deere tractors to iPhones, engineers have deliberately designed technologies to *not* be easily repaired by the user (Perzanowski, 2021). Those design choices were made with the priorities of the company in mind rather than those of society at large (see Fig. 1). The situation is potentially different for public sector engineers, which further emphasizes the overall point: if we are to examine the social and cultural influences on engineering, we need to pay close attention to the social contexts in which engineers work (Trevelyan, 2010).

To return to my broader argument, what needs to be recognized is that although engineering is certainly embedded in society, the *way* that it is embedded differs greatly from that of science. Science is influenced by the broader social context in various ways, such as the sources of funding for research (Erduran & Dagher, 2014; McComas, 2020; Wible, 1997). Importantly, though, science operates in ways that are intended to insulate it from that context. Unlike engineers, scientists need to function as a global community. Thus, many of the norms, values, and institutional structures of science exist precisely to serve as a bulwark against intrusions of the cultural context into the collective knowledge-building work (Allchin, 1999; Erduran & Dagher, 2014; Irzik & Nola, 2011; McIntyre, 2019; Vermeir, 2013). The institutions and organizations in which scientific research occurs (e.g., universities, government research laboratories) do play some role in terms of mediating social values, especially in terms of influencing which research areas are prioritized. But if institutions were to influence the technical conduct or results of scientific research, we would regard it as a significant breach of scientific norms and ethics.

If engineering is viewed through the lens of science, what is easily missed are not only the ways that values enter into engineering practice but also the *extent* to which engineering is value oriented. The technological products of engineering have direct and significant effects on individuals, society, and the environment. Those effects will not be equally distributed equally, and what is seen as benefits by some will be seen as costs and harms by others (Feenberg, 2010; Noble, 1991; Van de Poel & Kroes, 2014; Verbeek, 2005, 2011). Weighing and balancing those outcomes is not a strictly technical question, but one of values and priorities (Kranzberg, 1986; Mitcham, 2009; Roeser, 2012). Those questions will not be answered in the abstract, nor will they be answered solely by engineers, but rather will be negotiated by the social actors that are part of the professional engineering work setting (Bucciarelli, 2008; Meiksins & Smith, 1996; Suchman, 2000; Vincenti, 1990). Though not necessarily determinative, the values of engineers' employers and clients will be highly influential when value-based decision must be made (Conlon, 2008). In sum, context-specific social values are fundamental elements of engineering, not mere influences on an otherwise technical practice. As such, the sociocultural contexts in which engineering takes place play a central rather than peripheral role (Trevelyan, 2010).

The foregoing points indicate that descriptions of the sociocultural dimension of the NOE need to go beyond superficial discussions of how engineers are members of broad social communities. Among discussions of the NOE, Cunningham and Kelly's (2017) description of the "epistemic practices of engineering" is somewhat more attentive to the professional context of engineering. They point out how the parameters of an engineering problem are set by various stakeholders, including clients, customers, and end-users (though they do not explicitly mention the companies for which engineers work). In my previous work, I have provided a similar statement about how priorities "are negotiated by many stakeholders, including the industrial organizations in which the technology is being developed, the intended users of the technology, and the designers of the technology" (Pleasants & Olson, 2019, p. 14). However, these muted statements fail to capture the complexity and importance of the social structure of engineering and its relationship with sociocultural values. They can easily leave one with the impression that social forces are peripheral rather than central to engineering.

In sum, NOE frameworks (Antink-Meyer & Brown, 2019; Deniz et al., 2020; Pleasants & Olson, 2019) indicate that engineering is culturally embedded, but those descriptions are incomplete in crucial respects. Without attention to the organizations (companies, governments, etc.) in which engineers work, the sociocultural value judgments that occur during design cannot be fully understood. Moreover, the significance of those value judgments often goes unrecognized. My argument is that a major contributor to this oversight is the assumption that engineering is organized in ways that are analogous to science. There may be good reasons why nature of science frameworks do not foreground the universities and laboratories where scientists do their work. That choice, however, is less appropriate for the NOE.

4 Why These Issues Matter

Thus far, my focus has been on raising concerns and identifying gaps in extant NOE frameworks. Developing more accurate and precise descriptions of the NOE is worthwhile, but an important question is whether the concerns that I have raised are of great importance to precollege education. In this section, I take up that question directly. I argue that these are not esoteric details regarding the NOE, but aspects of engineering that are deeply important for teachers and students to understand. To build my case for why these ideas matter, it will first help to begin with an examination of why the NOE is regarded as valuable at all.

The case for learning about the NOE is typically made in relation to its relevance to the goal of developing students' engineering literacy (Antink-Meyer & Brown, 2019; ITEEA, 2020; Pleasants & Olson, 2019). Engineering literacy is typically positioned as something valuable for all students, regardless of their future careers (ASEE, 2020; NAE & NRC, 2009), a view captured well by the *Standards for Technological and Engineering Literacy* (ITEEA, 2020):

> The goal is not to make everyone technologists or engineers but to broaden technological and engineering literacy so that people can make informed decisions about technology and better contribute to its design, development, and use. (p. 3).

As is the case in the above statement, engineering literacy is typically conceptualized as being useful for making informed decisions in everyday life, echoing similar arguments about the value of scientific literacy (Feinstein, 2011; Roberts & Bybee, 2014). Just as the nature of science is considered useful for making decisions related to science (McComas & Clough, 2020), the NOE is thought of as useful for making decisions related to engineering and technology (ITEEA, 2020). But, as Feinstein (2011) reminds us, we should not make vague assumptions about why knowledge is useful. We ought to be clear about the everyday contexts in which that knowledge will be useful and how it will be used. Thus, I will need to make a case that understanding how engineers are situated within organizations has relevance for everyday decision-making.

To do this, I will examine specific examples of situations where a layperson would need to make decisions about engineering-related issues. I will begin with an example that concerns public sector engineering. Many municipal civil engineers are employed to work on problems of traffic flow. A city's complex system of roads and traffic controls (e.g., traffic lights, stop signs) presents a variety of design problems, and the choices that are made about those problems influence many people's daily lives. City residents ought to understand how traffic design decisions get made so that they not only better understand their environment (how come this intersection is designed this way?) but can also make their voices heard and contribute to its design (as suggested by the above quote from the ITEEA).

What might help a city resident engage with questions about the design of a city's traffic systems? There might be some value for a resident to understand the technical work of the traffic engineer: the specialized analytical tools, design methods, modeling strategies, and standards/regulations that they use. From the perspective of a city resident, though, understanding how different values are prioritized and make their way into design decisions is far more important than the technical details. Should an intersection be designed to prioritize the flow of automobile traffic? Along which corridors, and why? What consideration, if any, will be given to pedestrians? Or bicyclists? These are truly the pivotal questions, because once the priorities are established, the technical design will largely be routine.

Traffic engineers are not free to decide how to answer those questions (Conlon & Zandvoort, 2011; Lynch & Kline, 2000). They have a role to play, but understanding what is prioritized requires one to look at the broader organization of city government. There might be a board or commission that makes such choices, and municipal employees (e.g., the city manager, city planners) might also be involved. There are likely channels whereby residents and other stakeholders can provide input. These individuals, along with the engineer, each hold different amounts of decision-making power when it comes to defining the design problem to be solved. Demystifying these processes would enable a layperson to advocate for their own values and priorities. Engineers will not be the ones to decide that a city ought to be more walkable – but if that becomes a priority, they will be the ones to figure out how to put that goal into practice.

In the previous example, there are clear ways for a layperson to inform the design process, but what of private sector engineering? Here, the kinds of decisions that a layperson can make are different. Perhaps the most common way that laypeople engage with engineering is when they purchase and use technologies that engineers have designed. So, let us consider a decision that I (a non-engineer) might have to make about an everyday home appliance: which dishwasher should I purchase for my home? We can safely assume that engineers were involved (among many others) in designing just about any dishwasher that is available for purchase (Newberry, 2013). Because I am not and cannot be an expert on the technical systems themselves, my choice will need to be based on other cues. One thing that will be useful to consider is the kinds of priorities and values that guided the different design decisions that were made. In this case, the company is most crucial determinant of the values and priorities that guided the engineers' work.

Most of us would likely prefer to purchase a dishwasher that aligns with our own values and priorities. Let us consider just one of those priorities as an example: I would like a dishwasher that is reliable and long-lasting. After all, I would prefer not to have to make this decision again any time soon. Reliability is surely a consideration for any engineer who designs a dishwasher. But the extent to which it will be prioritized is a choice that will not be solely made by engineers. The engineers will need to start with the company's priorities and concerns (not mine) and translate them into technical requirements (Kroes, 2012; Newberry, 2013; Vincenti, 1990). The company does not necessarily mind me needing to buy a new dishwasher; though if the dishwasher doesn't last a reasonable amount of time, I'm unlikely to buy one from that company again. Also, if the company offers some kind of manufacturer's warranty (say, for 3 years), then a lack of reliability will be costly for the company. Hopefully the engineers will not be tasked with making sure that a dishwasher will fall apart after 5 years (though this is not an impossibility). But even if we ignore that pernicious scenario, there is no reason to assume that a product was engineered for longevity. A company does not necessarily benefit much from producing dishwashers that last a lifetime. But what if the company offers a very long warranty on their product, say 20 years or more? In this case, I likely *can* assume that the engineers were explicitly given reliability and longevity as design priorities. I should have confidence in this product not just because the company is willing to fix or replace it, but because the company almost certainly directed its engineers to make sure that very little fixing or replacing will need to occur.

When products don't last, there is an urge to call it "bad design" (Green, 2021), but this is misleading. The problem isn't one of design as such, but of the values and priorities of companies versus those of consumers (Cooper, 2010; Jordans, 2021; Laitala et al., 2021). Unlike the public sector example, there are no straightforward channels for the layperson to inform design decisions. Nevertheless, thinking about how decisions get made within an organization is helpful when making choices about technology. When engineers design new or different technologies, they do not and cannot make them "better" in some universal sense (Kroes, 2012; Mitcham, 1994; Noble, 1991; Volti, 2005). As laypeople, it is valuable to consider what outcomes a technology was optimized for, and why.

There is, of course, much more that can be said regarding issues of transportation and home appliances. My goal here is not to give those issues a comprehensive treatment, but to illustrate the relevance of the NOE for engaging with them. More specifically, these examples show the importance of paying attention to the professional contexts in which engineer do their work. My insistence that we pay greater attention to those contexts when discussing the NOE is therefore not simply because I desire a more comprehensive or detailed account. There is, after all, always a more complex and detailed account to be had. The value of adding those details depends upon their contribution to engineering literacy – in their usefulness for making decisions in the world. As the preceding examples indicate, the ideas about the NOE that I have developed in this paper are indeed useful.

Importantly, the examples discussed above illustrate how examining the professional contexts of engineering reveals the ways that engineering intersects with values. From the standpoint of engineering literacy, understanding how values are negotiated within engineering needs to be a high priority. For one, it points to an important difference between science and engineering. While both science and engineering are value-laden (Kroes, 2012), they make contact with social values in distinctly different ways. Moreover, it challenges the problematic message that engineering is a purely rationalistic, technical, and value-neutral practice (Cech, 2014, 2015; Gravel & Svihla, 2021; Roeser, 2012; Trevelyan, 2010). In common discourse, engineering values are often narrowly defined as ones that ensure safety and avoid direct harm (Bucciarelli, 2008; Herkert, 2001; Swierstra & Jelsma, 2006). Or, alternatively, engineering is vaguely and abstractly described as pursuing "public welfare" (Bucciarelli, 2008; Mitcham, 2009). Such notions serve neither the lay public nor engineers, and learning about the NOE can and should help all students develop a deeper understanding of engineering as value-driven work.

5 Moving NOE Research Forward

My goal in this paper has been to raise concerns with the frameworks that currently underpin the nascent area of NOE research. A recurring theme in my argument is that, while there is certainly much that can be learned from the extensive research on the nature of science, we must be cautious when transporting those concepts to the NOE. Leaning too heavily on nature of science ideas can lead to conceptual missteps, as in the case of describing epistemic aims and values of engineering (Barak et al., 2022), or insufficient inattention to important concepts, as in the case of describing the cultural embeddedness of engineering (Antink-Meyer & Brown, 2019; Deniz et al., 2020; Pleasants & Olson, 2019). In addition to urging caution, I have further argued that the organizational structure of engineering is an important NOE dimension for building engineering literacy. Incorporating this idea into NOE frameworks and into precollege engineering education opens interesting possibilities for teaching and learning. Rather than treating engineering as a wholly technical practice of problem-solving, foregrounding the professional contexts in which engineering occurs forces us to think about engineering as a value-oriented activity. That, in turn, invites inquiry into the values that organizations currently pursue, and which ones we might *prefer* that they pursue.

To give but one example, consider the ways that many supply chains have been designed (by engineers) for economic efficiency rather than resiliency. The supply chain breakdowns that occurred during the COVID-19 pandemic were not the result of sloppy engineering; most global supply chains have been very skillfully designed from a technical perspective. The issue is that the redundancies needed for resilience are incompatible with efficiency, and efficiency is what the social actors within companies chose to prioritize (Ozdemir et al., 2022). Armed with an understanding of the organizational aspect of the NOE, we can see why supply chain engineers were tasked with designing such a fragile, but highly efficient, system. We can also see why addressing the problem of resiliency will not strictly be one of *more* engineering but rather of *different* engineering (Ozdemir et al., 2022; Spieske & Birkel, 2021). And we won't get different engineering unless organizations change their priorities.

Addressing this aspect of the NOE opens up the opaque processes by which the requirements of a design problem are established. Many have argued that precollege engineering education ought to help students understand design requirements (ASEE, 2020; Cunningham & Carlsen, 2014; ITEEA, 2020; NAE & NRC, 2009), but surprisingly little attention is given to how those requirements are negotiated in the real world. In terms of promoting engineering literacy, understanding where requirements come from is likely to be more useful than learning how to engage in engineering practices oneself. Looking ahead, the question is how this aspect of the NOE might be taught in in the context of precollege engineering instruction. Perhaps this could be done by taking a "reverse engineering" approach (Purzer et al., 2022). For instance, students might examine the products created by a company that claims to value sustainability. In what ways, and to what degree, are those products aligned with that value? What other values might have competed with sustainability in terms of the design choices that engineers made for those products? How could the products have been designed more sustainably, and why weren't those decisions made? Engaging with such questions allows engineering education to be about more than the procurement of strictly technical skills and ways of thinking (Cech, 2014; Roeser, 2012; Rulifson & Bielefeldt, 2018; Trevelyan, 2019).

Another contribution of this work is its engagement with the question of which NOE ideas are most valuable in terms of their contributions to engineering literacy. Too often, we simply assume that knowledge, whether of the NOE, technical concepts, the nature of science, or anything else, will be helpful for students to know in their adult lives. The value of many ideas is justified in terms of their relevance for scientific or engineering literacy, but we rarely articulate exactly how those ideas will be useful for making decisions in life (Feinstein, 2011). Not every aspect of the NOE that has been described in the literature is necessarily a priority for precollege engineering education. As researchers continue to develop and refine NOE frameworks (e.g., Barak et al., 2022), instruments for assessing the NOE (e.g., Antink-Meyer & Brown, 2020; Kaya, 2020; Kaya et al., 2023; Pleasants, 2021), and approaches for teaching the NOE (Deniz et al., 2020; Driessen et al., 2023; Pleasants, 2022), we must not avoid conversations about priorities. This paper will hopefully serve as a step in that direction.

Declarations

Conflict of Interest The author declares no conflict of interest.

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