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ARTICLE

Rethinking the Dual Nature of Science

A Synthetic Framework for Cognitive-Epistemic and Social-Institutional Analysis Through Wittgenstein and Bourdieu

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Abstract

The Nature of Science (NOS) has long been a central focus in science education, with scholars examining its processes and structures from diverse perspectives. One influential approach builds on Ludwig Wittgenstein's family resemblance concept, which conceptualises NOS as an interplay between cognitive-epistemic and social-institutional systems. While this framework offers valuable insights into the fluid boundaries between these domains, it overlooks critical aspects such as power dynamics, cultural influences and institutional structures that shape scientific practice. To address these gaps, this paper integrates Wittgenstein's ideas with Pierre Bourdieu's *Theory of Practice*, particularly his concepts of habitus, field and capital. Bourdieu's framework complements Wittgenstein's emphasis on the fluidity and variability of practices by highlighting how cultural norms, power relations and institutional structures influence both the cognitive and social dimensions of science. The philosophical alignment between these perspectives is explored, alongside counterarguments to critiques, demonstrating their compatibility in analysing scientific practices. Building on this synthesis, the paper expands the family resemblance approach to NOS framework, emphasising the dynamic interactions between scientific practices and their broader social contexts. It advocates for a more inclusive and reflexive model of NOS that acknowledges the role of power and cultural influences in shaping scientific knowledge and supports reflexive pedagogy for a more equitable and dynamic science education framework.

1 Introduction

Since its inception, the Family Resemblance Approach (FRA) to the nature of science (NOS) (Erduran & Dagher, 2014; Irzik & Nola, 2011, 2014) has become a widely used framework in science education. FRA conceptualises NOS as a dynamic system comprising aims, values,

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practices, methodologies and social norms that should be reflected in the curriculum. Drawing from Wittgenstein's (1958) philosophy, FRA highlights that while scientific disciplines share characteristics, none alone defines science. Irzik and Nola (2011) introduced FRA by focusing on activities, aims, values, methodologies and products of science. Later, they expanded it to include social-institutional dimensions (Irzik & Nola, 2014), emphasising science as both cognitive and social practice.

Building on these ideas, Erduran and Dagher (2014) incorporated political, financial and organisational elements of science, offering visual tools for education. Their contribution has made the complexity of NOS more accessible to educators (Cheung & Erduran, 2022; Cheung et al., 2024a, 2024b; Erduran et al., 2019). The framework's influence has since extended beyond science education to fields like engineering (Barak et al., 2024), geography (Puttick & Cullinane, 2022) and even discussions on pseudoscience (Park & Brock, 2023). This expansion was further evidenced by a special issue of *Science & Education* (Barak, 2023), which emphasised FRA's role in bridging epistemology, practices and social structures, underscoring its ongoing relevance to NOS research.

A key issue that arises from this discourse is the relationship between science's cognitive-epistemic and social-institutional systems. This paper contends that Pierre Bourdieu's sociological concepts—habitus, field and capital—offer valuable tools to explore this relationship. Erduran and Dagher (2014) argue that these systems are not rigidly divided but instead exhibit porous boundaries, enabling fluid movement across them. While previous qualitative (e.g. Dagher & Erduran, 2016; Yeh et al., 2019) and quantitative studies (e.g. Cheung, 2020; Cheung et al., 2023) have explored these linkages within curricula, media and policy (see also a systematic review by Cheung & Erduran, 2022), many do not go far to address the role of social and mental structures that influence the production and validation of scientific knowledge. As such, there remains a need for further analysis of how power dynamics, institutional hierarchies, personal dispositions (habitus) and socially recognisable resources (capitals) shape the legitimacy of scientific knowledge in education (Erduran, 2023).

This paper proposes using Pierre Bourdieu's (1977, 1980) *Theory of Practice* to address these gaps. Specifically, it will focus on how the concepts of habitus, field and capital interact with scientific practices and power dynamics. By investigating how cognitive and social factors influence scientific activity, this paper aims to deepen understanding of science as both a cognitive and socially embedded activity. The discussion begins with an overview of FRA and its role in conceptualising NOS, followed by an exploration of Bourdieu's theoretical lens in science education. The paper then examines how Bourdieu's framework aligns with Wittgensteinian perspectives, showing how both frameworks contribute to a more comprehensive understanding of NOS. Finally, it illustrates how elements of Wittgenstein's philosophy, as articulated by Erduran and Dagher (2014), can be enriched by Bourdieu's concepts, shedding light on how cognitive and social systems work together to shape science as a cohesive yet dynamic system. Through this analysis, the paper aims to provide new insights into the complexity of scientific practices and offer practical implications for science education.

2 Family Resemblance Approach to Nature of Science

The Family Resemblance Approach (FRA) to the Nature of Science (NOS) was developed by Gürol Irzik and Robert Nola (2014) to offer a comprehensive, systematic understanding of science. Rooted in Wittgenstein's philosophy, FRA posits that science cannot be defined by a single set of traits but instead features shared and distinct elements across its sub-disciplines. This framework highlights science as a cohesive yet diverse system, emphasising its dual nature: a *cognitive-epistemic system* (including inquiry, aims, values, methods and scientific knowledge) and a *social-institutional system* (encompassing scientific ethos, social certification, dissemination and professional activities). While these two systems are conceptually distinct, they remain interconnected, reflecting the complex interplay between cognitive processes and social practices in science.

Building on Irzik and Nola's work, Erduran and Dagher (2014) expanded the FRA to include categories like political power, financial systems and social structures, providing a more holistic view of science. They introduced visual tools such as the FRA Wheel (Fig. 1), which illustrates science's dynamic and interactive nature. The wheel's porous boundaries highlight the fluid movement between categories, symbolising how cognitive and social elements influence each other. This visualisation allows educators to introduce NOS concepts with flexibility, focusing on context-specific elements while maintaining a comprehensive perspective. The FRA Wheel promotes an interconnected, non-linear understanding of science that resonates with science education goals.

The FRA's educational value lies in its ability to integrate NOS into curricula, encouraging teachers to address both cognitive and social dimensions. Educators can tailor NOS instruction, focusing on specific components like epistemic inquiry (e.g. observation, experimentation) or social-institutional dimensions (e.g. peer review, consensus-building) without needing to cover every category in detail. This flexibility makes the FRA a useful tool for addressing the complexity of science education. By enabling stakeholders to contextualise the NOS within diverse learning environments, the FRA supports a more authentic representation of science's nature (Dagher & Erduran, 2016; Erduran & Dagher, 2014).

The FRA's relevance is further underscored by the *Science & Education* journal's special issue on the topic (Barak, 2023), which addresses its theoretical and practical applications. While revisiting the theoretical foundations of the FRA (Dagher & Erduran, 2023; Irzik & Nola, 2023; Park & Brock, 2023), articles from countries like Turkey (Okan &

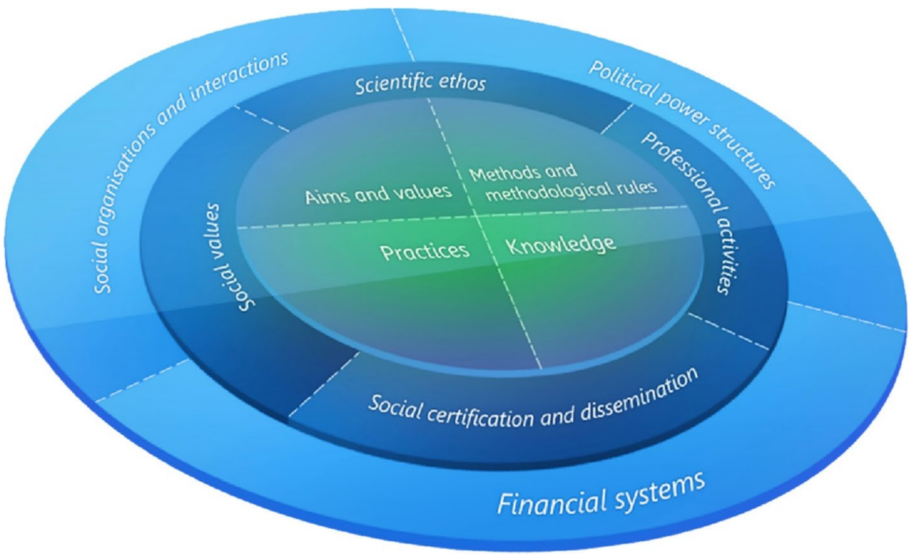

Fig. 1 FRA Wheel from Erduran and Dagher (2014)

Kaya, 2023), South Africa (Yeh et al., 2023), Germany (Fricke & Reinisch, 2023) and Norway (Kostøl et al., 2023) how different aspects of NOS are addressed in curricula and textbooks, highlighting their potential impact. Empirical research highlights the FRA's potential to transform science education through curriculum analysis, textbook evaluations and teacher development. However, challenges remain. For example, Takriti et al. (2023) report that pre-service teachers often confuse concepts like bias and politics in science, while Voss et al. (2023) show that teachers progress from implicit to explicit NOS instruction after engaging in reflective practices. Additionally, Demirel et al. (2023) reveal that teachers frequently conflate 'scientific practices' with 'scientific methods', leading to conceptual misunderstandings. These studies highlight the need for targeted professional development to ensure educators can effectively convey the richness of NOS concepts in classrooms (Dagher & Erduran, 2023).

The guiding question of this paper arises from the insights provided by the FRA: How do the cognitive-epistemic and social-institutional dimensions of science interact? While prior studies have addressed links between these dimensions, there is a growing recognition of the role of social structures, power and habitus in shaping scientific practice. To address this, this paper integrates Pierre Bourdieu's sociological theory, particularly his concepts of habitus, field and capital, to explore the inherent power dynamics within science. By investigating how Bourdieu's framework aligns with FRA, this paper aims to provide a richer, more nuanced view of NOS, focusing on how power, social position and symbolic capital influence the production, validation and dissemination of scientific knowledge. Through this exploration, the paper offers a more sophisticated conceptualisation of NOS, highlighting the interplay between cognitive and social elements in science. By applying Bourdieu's framework to the FRA, it addresses critical issues related to institutional power, social hierarchies and the role of capital in scientific legitimacy, providing fresh insights for educators, policymakers and curriculum developers. The next section contextualises Bourdieu's Theory of Practice and explores its implications for understanding NOS and its application in science education.

3 Bourdieusian Lens to Science Education

Bourdieu's sociological theories offer a valuable lens for understanding science education, particularly through the concepts of habitus, field and capital. These concepts help explain how students' social backgrounds shape their engagement with science. *Capitals*, such as economic (financial assets), cultural (knowledge and tastes) and social (networks and memberships), are socially recognisable resources that shape students' success. Science capital, a concept extended from Bourdieu's work by Louise Archer and colleagues, includes scientific knowledge, attitudes, social networks and cultural resources that influence students' science participation. Students with high science capital are more likely to view science as relevant to their lives and pursue it academically (Archer et al., 2015). This framework highlights barriers to science engagement, especially for underrepresented groups, and provides strategies to address them. Archer et al. (2018a) explore science classrooms as *fields*—social spaces where the value of a student's capital is assessed. The interaction between a student's *habitus* (internalised dispositions) and the classroom field determines whether they feel science is 'for them'. This approach underscores how social position, rather than inherent ability, influences engagement. While the approach helps educators design inclusive lessons, it also reveals the tension between equity and the demands of standardised education systems, which often prioritise measurable outcomes over deeper engagement.

Another key Bourdieuian concept relevant to science education is symbolic violence—the subtle reinforcement of social hierarchies through educational practices. Archer et al. (2018b) argue that ability grouping in schools appears neutral but often perpetuates class, race and gender inequalities. Students from disadvantaged backgrounds (e.g. Black, working-class students) are more likely to be placed in lower sets, leading to reduced expectations and limited opportunities for advancement. Archer et al. (2020) also examine gender disparities in physics, highlighting how gendered habitus and the symbolic capital associated with physics as a male-dominated field push young women away from the subject. This analysis shows how Bourdieu's concepts critique 'neutral' practices that, in reality, reinforce inequalities.

The development of the Science Capital Teaching Approach (Archer et al., 2024) is one of the most significant applications of Bourdieu's work in education. This model integrates culturally sustaining pedagogy with Bourdieu's science capital framework, encouraging teachers to connect science lessons to students' everyday experiences, involve families in learning and partner with local science organisations. The goal is to build students' knowledge, skills and networks, enabling them to navigate the science education system and access science-related careers. This approach challenges traditional views of science as culturally neutral, instead valuing students' diverse social and cultural backgrounds.

Bourdieu's framework also applies to informal science learning (e.g. after-school clubs, zoo visits) (Archer et al., 2021; Dawson, 2014; Gokpinar & Reiss, 2016). Informal learning spaces help students develop a scientific habitus and accumulate science capital through hands-on experiences. However, intentional program design is essential to address the social and cultural barriers faced by underrepresented groups. Programs that connect science to students' lived experiences are more likely to foster meaningful engagement and increase students' long-term interest in science (Claussen & Osborne, 2013; Dawson, 2014; Gokpinar & Reiss, 2016; Mendoza et al., 2012). These applications of Bourdieu's work in science education emphasise the importance of recognising the diverse forms of capital and associated habitus that students and teachers bring to the classroom. Teachers who understand the role of *habitus* are better equipped to design lessons that resonate with their students' lived experiences.

Bourdieu's concepts of habitus, field and capital, provide a comprehensive framework for identifying barriers to science participation and guiding inclusive practices. Archer's application of Bourdieu's theories has been instrumental in critiquing practices like ability grouping, rethinking gender disparities in physics and promoting culturally responsive pedagogy. These ideas align with the FRA-NOS as proposed by Erduran and Dagher (2014), which calls for a more socially aware model of science education (Erduran, 2020; Erduran & Ioannidou, 2024; Erduran et al., 2020). Together, Bourdieu's and Wittgenstein-inspired FRA frameworks highlight science as a cognitive and social endeavour, promoting a more equitable, inclusive education system. The next section explores the philosophical compatibility of Bourdieu and Wittgenstein and the critiques of their theories.

4 Bourdieu and Wittgenstein

4.1 Philosophical Compatibility

Pierre Bourdieu's sociological theories and Ludwig Wittgenstein's philosophical perspectives have had a profound impact on the humanities, social sciences and science education.

While Bourdieu is best known for exploring social structures and power dynamics (e.g. Archer et al., 2021; Dawson, 2014; Gokpinar & Reiss, 2016), Wittgenstein focused on the philosophy of language and meaning (e.g. Erduran, 2022; Heckler, 2014; Wu & Erduran, 2022). Despite their differences, their concepts converge in meaningful ways, especially in understanding how social practices shape cognition and behaviour. Although no major study has yet combined their insights in science education, examining the intersection between their theories offers valuable perspectives on social systems and learning.

To explore their compatibility, it is important to understand their key concepts. Bourdieu's (1977, 1980) framework includes habitus, field and capital, which explain how social life is structured and maintained. Fields are social arenas with distinct rules ('logic of practice') where people and institutions compete for symbolic capital—prestige, recognition or legitimacy. Symbolic capital is linked to other forms of capital, such as economic (e.g. funding), social (networks and connections) and cultural (scientific knowledge and competencies). Habitus refers to the internalised dispositions shaped by one's social background, guiding how individuals perceive and act within fields. On the other hand, Wittgenstein's (1958) theory centres on 'practices' as language games—rule-governed activities where the meaning of language is defined by its use within specific social contexts (Lovibond, 2022). According to Wittgenstein, understanding language requires looking at the social practices in which it operates. These practices are not isolated but embedded in 'forms of life'—shared activities with implicit rules. To perform an action, one must understand these constitutive rules, making the action inherently social. Practices integrate social rules within individual actions and can be seen as a public system specifying rights, duties and roles within a group, such as political institutions, conventions, rites or games like football and chess. Just as Bourdieu's 'logic of practice' governs the rules of a field, Wittgenstein's language games highlight the contextual and rule-bound nature of meaning, illustrating how human behaviour is shaped by social participation (Kennedy, 2016).

The compatibility between Bourdieu and Wittgenstein lies in their shared emphasis on social practices (Croce, 2015; Stirk, 1999; cf. Frost & Lechner, 2016). Both theorists argue that human action is shaped by implicit rules operating within shared activities. For Wittgenstein, these rules are embedded in language games that define how language is used within social contexts. For Bourdieu, fields represent structured social spaces governed by specific rules and norms. In both perspectives, social practices are inherently relational and contextual, and they depend on the shared participation of agents. Rules and structures are another area where their theories align (Gerrans, 2005; Stirk, 1999). Wittgenstein describes the rules of language games as flexible and dynamic, changing with use and context. Bourdieu's concept of the field similarly describes a system where the 'rules of the game' shape participants' actions and are subject to change. Bourdieu's habitus also reflects this flexibility, allowing agents to navigate fields based on past experience. This mutual recognition of the fluid, situated nature of practices reveals their shared perspective on structure and agency. While Bourdieu frames these practices as sites of power and competition, Wittgenstein frames them as sites of meaning-making, but both perspectives highlight the interplay of individual action and social structure (King, 2000).

A key difference between Bourdieu and Wittgenstein lies in their treatment of power. Bourdieu emphasises that social fields are arenas of competition for power, with symbolic power playing a critical role (Bourdieu & Wacquant, 2013). Symbolic power enables dominant groups to impose meanings that become legitimised within the field (Bourdieu, 1989). Power is embedded in language, social norms and cultural artefacts, and it shapes which voices are heard and which are marginalised. Wittgenstein, by contrast, does not focus explicitly on power, but his concept of language games reveals how social norms and implicit rules structure human interaction (Croce, 2015). This difference is evident in how their ideas relate to science education. For example, in the peer review process, Wittgenstein's perspective can be seen in how scientists use language within the 'game' of academic publishing, while Bourdieu's perspective shows how the field of science is shaped by symbolic power and cultural capital, which determine which knowledge is legitimised (Zou, 2024). Together, the integrated frameworks reveal how micro-level linguistic practices (Wittgenstein) and macro-level social structures (Bourdieu) shape scientific knowledge production and dissemination.

In summary, Bourdieu and Wittgenstein converge on the importance of context, practice and rules. Their combined insights offer a powerful lens for understanding human action and social order. While Wittgenstein focuses on language games and meaning, Bourdieu focuses on power and symbolic capital. Together, their ideas reveal how practices are structured, legitimised and sustained through social participation. While Bourdieu and Wittgenstein share significant theoretical compatibilities, their integration also presents conceptual tensions. The next section will discuss the critiques and counterarguments in details.

4.2 Critiques and Counterarguments

This paper acknowledges the potential conflicts of the integration of Bourdieu and Wittgenstein's philosophy that need meticulous navigation (Bernasconi-Kohn, 2013; Curry, 2002; Gerrans, 2005; Medina, 2003; Schatzki, 1997; Stirk, 1999). Critics suggest Bourdieu's focus on social structures and power may overshadow Wittgenstein's emphasis on the fluidity of language practices. Conversely, Wittgenstein's language games risk neglecting the broader social and political contexts central to Bourdieu's framework.

One major issue is relativism in their philosophical assumptions. Bourdieu's sociology of science, particularly in *Science of Science and Reflexivity* Bourdieu (2001) and in *Pascalian Meditations* Bourdieu (2000), addresses relativism by asserting that truths produced in autonomous scientific fields are 'trans-historical' (Kale-Lostuvali, 2016). However, some argue this perspective overemphasises structural determinism, potentially undervaluing individual agency (Verweij, 2008). Habitus, a core concept in Bourdieu's theory, has been critiqued as deterministic, though Bourdieu counters this by describing it as a generative structure that enables adaptation to change (Wacquant, 2016). In contrast, Wittgenstein's language games stress flexibility and adaptability, focusing on how individuals navigate and reshape meaning within contexts (Cheung et al., 2024a, 2024b). While this highlights individual agency, it can seem disconnected from the structural power dynamics Bourdieu explores. However, both theorists acknowledge the interplay of structure and agency: Bourdieu emphasises constraints shaped by power, while Wittgenstein highlights the evolving nature of linguistic rules through social interaction (Croce, 2015).

Empirical studies illustrate how integrating these perspectives can enhance science education. Archer et al., (2018a, 2018b) demonstrate this in their study on a Bourdieusian-inspired pedagogical approach implemented in London schools. Teachers and students engaged in reflexive classroom practices that both reinforced and challenged existing power dynamics, aligning with Bourdieu's concept of habitus while incorporating the adaptability found in Wittgenstein's language games. Similarly, Archer et al. (2015) extend Bourdieu's notion of capital to introduce *science capital*, highlighting how linguistic practices shape students' access to scientific knowledge while being embedded in broader institutional structures. Their findings support the argument that science learning is influenced both by the rules of discourse within classrooms and by the wider social fields that determine whose knowledge is valued.

A second critique targets the scope of Wittgenstein's language games. His micro-level analysis may overlook macro-level dynamics, such as the social fields and symbolic power central to Bourdieu's theory (Norris, 2003). Language games offer valuable insights into localised practices, but they need to be contextualised within broader societal structures to fully capture the interaction of power, culture and language. For instance, Archer et al., (2018a, 2018b) highlight the symbolic violence of ability grouping in science classrooms, showing how institutional structures perpetuate inequalities through seemingly neutral linguistic and pedagogical practices. This demonstrates how macro-level social forces shape micro-level interactions, reinforcing Bourdieu's assertion that symbolic power is exercised through everyday discourse. Furthermore, Archer et al. (2021) illustrate how informal science learning programs can disrupt these traditional power structures by creating alternative spaces where students from underrepresented backgrounds can develop a sense of belonging in science. These programs challenge dominant language games in science education while reshaping the social field in which they operate.

These critiques ultimately underscore the potential for a unified framework combining Bourdieu and Wittgenstein's theories. A unified approach combines Bourdieu's attention to social structures, power and capital with Wittgenstein's focus on the rules and context of linguistic meaning. This combined framework highlights how individuals engage with social systems while also exercising agency. It accounts for both macro-level constraints (through field, habitus and symbolic power) and micro-level flexibility (through language games and everyday interactions). Such a perspective is particularly useful for analysing educational, cultural and political institutions, offering a comprehensive view of how individuals negotiate and challenge social structures through language and practice. The following section will demonstrate how Bourdieu's concepts of habitus, field and capital illuminate science as both a cognitive pursuit and a socially embedded practice, illustrating how knowledge production is shaped by the interplay between micro-level practices and macro-level structures.

5 (Re)thinking NOS with Bourdieu

Erduran and Dagher's (2014) FRA-NOS framework draws on Wittgenstein's Family Resemblance approach to highlight the fluid and context-dependent NOS. Rather than adhering to a fixed set of criteria, NOS is seen as a network of overlapping similarities among scientific practices, concepts and methods. Bourdieu's sociological theories build on this by revealing how social structures, power relations and cultural capital shape these practices. His concepts of field, capital and habitus illustrate how cognitive-epistemic and social-institutional dimensions of NOS are intertwined, with scientific knowledge production influenced by both internal norms and external sociopolitical forces.

5.1 Cognitive-Epistemic System

Bourdieu extends the Wittgensteinian exploration of the cognitive-epistemic system (Table 1) by integrating his concepts of field, habitus and capital to reveal how social structures and power dynamics shape scientific aims, methods, practices and knowledge production. His framework challenges the view of science as purely objective, emphasising its deep entanglement with broader societal contexts where stakeholders compete to legitimise and advance their research. This perspective enriches the understanding of science as a socially embedded enterprise, shaped by both internal principles and external sociopolitical forces.

5.1.1 Aims and Values: Habitus and Scientific Goals

Scientific aims and values are not about finding 'the right answer' but about internalising the norms and practices essential for conducting scientific inquiry (Erduran & Dagher, 2014, p. 49). Using Bourdieu's concept of habitus, we can understand how these values are embodied and perpetuated by scientists, educators and students. For scientists, deeply internalised aims such as objectivity, rigor and empirical validation become second nature. However, these aims are also influenced by external societal pressures (Longino, 2020). Educators play a critical role in transmitting these values to students, but this process is not neutral (Guilfoyle et al., 2024; Kelly & Erduran, 2019). Instead, social inequalities embedded in educational systems affect how these values are internalised. Families and educators may navigate the system to confer advantages on certain students—often those from more privileged backgrounds (Lareau et al., 2016). This process, termed the 'transmission of advantage', affects how students perceive their place in science, with privileged students often seeing themselves as naturally aligned with scientific goals, while others may feel excluded. These dynamics highlight how social class and privilege shape the transmission of scientific aims. Students in higher-status schools are more likely to see themselves as 'natural' participants in the scientific enterprise. This process reinforces existing social hierarchies and creates unequal access to opportunities in science (Davey, 2012).

In response, pedagogy should explicitly challenge these patterns by fostering inclusive classroom environments that emphasise the shared epistemic values of science. Erduran and Dagher (2014) advocate for developing a 'common language for approaching, conducting, and interpreting scientific activities' (p. 49). A critical goal of science education is to cultivate a 'deep commitment to scientific aims and values' while helping students internalise scientific principles in ways that are meaningful and inclusive (Erduran & Dagher, 2014, p. 54). From a Bourdieusian perspective, this process requires confronting how social background shapes students' engagement with scientific aims. Teachers should encourage students to critically assess how science interacts with broader power structures. By explicitly teaching the social dimensions of science, educators can challenge the inequalities that influence which students feel 'at home' in scientific fields.

5.1.2 Methods: Fields and the Rules of Scientific Methods

Scientific methods are governed by 'a number of methods and methodological rules' (Irzik & Nola, 2014, p. 1003), which vary across scientific domains. These rules are not fixed but evolve according to the specific needs of each field. Erduran and Dagher (2014) challenge the idea of a single 'universal method' for science, emphasising instead the diversity of methodological practices. Bourdieu's concept of the field provides a sociological lens to understand how methods are shaped by power, authority and social capital within scientific communities. In Bourdieu's framework, the field is a dynamic social space where agents (scientists) compete for legitimacy and symbolic capital. The selection and validation of methods within this field are not neutral but are influenced by power hierarchies. Established scientists with greater symbolic capital have more freedom to innovate or introduce

Table 1 The cognitive-epistemic of NOS: Wittgensteinian (Erduran & Dagher, 2014) and Bourdieusian (authors' elaborations) approaches to NOS and pedagogy

Categories	Definitions	Wittgensteinian approach	Wittgensteinian FRA to pedagogy	Bourdieusian approach	Bourdieusian-inspired FRA to pedagogy
Aims and Values	Goals that guide scientific inquiry and values that shape its conduct	Aims and values are internalised through shared language games, supporting objectives like objectivity and rationality	Foster students' internalisation of core values like scepticism, objectivity and social responsibility. Students co-construct these aims through collaborative inquiry	Aims are shaped by the habitus of scientists and social structures. Privileged groups' values become dominant norms, and social hierarchies shape how students internalise these values	Foster students' critical reflection on how aims and values are socially shaped. Expose students to diverse perspectives on aims like equity and societal impact, addressing how power structures shape scientific goals
Methods	Rules and procedures used in scientific inquiry	Methods are seen as shared 'rules of the game', emphasising domain-specific practices rather than a single 'scientific method'	Teach diverse methods across disciplines, encouraging students to engage with different forms of data collection, analysis and validation	Methods reflect the power dynamics in the field. Dominant groups' symbolic capital determines which methods are legitimate	Expose students to how power shapes methodological choices. Highlight cases where marginalised approaches were excluded, fostering student critique of the perceived 'neutrality' of methods
Practices	Activities like classification, modelling and experimentation that produce knowledge	Practices are understood as shared social norms embodied in scientific activities. Language games guide practices like classification and model development	Emphasise diverse scientific practices (e.g. modelling, classification) and encourage students to engage in collaborative, inquiry-based work	Practices are shaped by power relations, with privileged actors shaping norms. The concept of habitus explains why some students experience practices as familiar while others feel excluded	Highlight how practices are not neutral but shaped by social structures. Create equitable access to scientific practices, especially for marginalised groups, and challenge dominant norms that restrict student participation

Table 1 (continued)

Categories	Definitions	Wittgensteinian approach	Wittgensteinian FRA to pedagogy	Bourdieusian approach	Bourdieusian-inspired FRA to pedagogy
Knowledge	Coherent systems of scientific theories, laws and models	Knowledge is presented as an interconnected system (theories, laws, models) that evolves through scientific language games	Teach how scientific knowledge is dynamic and context-dependent, fostering students' understanding of scientific explanations and classification systems	Knowledge is a form of symbolic capital that reflects social hierarchies. Dominant groups control which knowledge is legitimised and valued	Teach students to critically examine whose knowledge is included or excluded in science. Highlight diverse perspectives, encouraging students to analyse how power dynamics affect the acceptance of scientific ideas

unconventional methods, while early-career researchers often conform to traditional methodologies to gain legitimacy. Habitus—the internalised dispositions of researchers—also shapes method selection, as scientists are more likely to use methods that align with their socialisation and training (Longino, 2020).

These dynamics influence the experience of students in science education. Students from privileged backgrounds, with greater cultural and social capital, are more likely to feel 'at home' with scientific methods, while students from less privileged backgrounds may see these methods as rigid or alienating (Godec et al., 2018). Such experiences mirror the broader power structures within the field, where dominant epistemological norms are legitimised while alternative perspectives are marginalised. The privileging of specific methods, such as subscribing to 'a single, universally applicable method invariant' or 'discriminating between acceptable sources of evidence and determining appropriate data-gathering methods' (Erduran & Dagher, 2014, p. 95–96), exemplifies what Bourdieu calls symbolic violence (Bourdieu, 1991), excluding certain students from full participation in scientific inquiry, even when they understand the 'rules of the game'. To address this, science pedagogy should explicitly recognise and value the diversity of methods. Educators should emphasise how methods are socially shaped and highlight the broader array of tools and evidence available for scientific inquiry. This approach can help students critically evaluate how methods are selected and challenge exclusionary norms. A more inclusive approach to method teaching allows students from diverse social backgrounds to see themselves as legitimate participants in scientific inquiry, thereby fostering broader engagement and equity.

5.1.3 Practices: Embodied Institutional Norms

Cognitive-epistemic practices,[1] including activities like modelling, classification and data analysis, are essential to the production of knowledge. These practices are not isolated technical processes but are embedded within broader epistemic, cognitive and social-institutional contexts (Erduran & Dagher, 2014). From a Bourdieusian perspective, scientific practices are shaped by power, authority and symbolic capital within the field. Classification, a fundamental scientific practice, illustrates these dynamics. Classification involves organising concepts, entities or data in ways that support scientific reasoning. As Erduran and Dagher (2014, p. 76) note, '[t]he preceding examples from biology and chemistry not only illustrate how classification can operate in science in broad terms but also point to particular epistemic features of classification as a practice'. While it may appear as a purely technical process, classification reflects the social power and authority of those who define the categories. Scientists with greater symbolic capital (e.g. senior researchers or influential institutions) have more power to determine which classifications are accepted as legitimate. This power to classify mirrors Bourdieu's concept of the field as a site of struggle, where dominant actors impose epistemological norms that shape knowledge production. Habitus also plays a role, as researchers' internalised dispositions influence how they classify phenomena based on their training, experience and socialisation within the field.

These power dynamics have profound implications for education. For example, Herbaut and Barone (2021) demonstrate how gendered practices contribute to lower career

[1] In this paper, 'cognitive-epistemic practices' refer to practices in the FRA framework, while in all other cases, 'practices' are understood in the Bourdieusian sense as socially situated activities shaped by habitus, field and capital.

ambitions among girls in science, reflecting broader social structures that influence student engagement. Students from privileged backgrounds, who are more familiar with scientific norms and have greater cultural capital, are more likely to develop practical mastery (Schatzki, 1987) of scientific practices. Their habitus aligns with the expectations of the scientific field, allowing them to internalise scientific processes naturally. In contrast, students from marginalised or underprivileged backgrounds may face barriers due to a misalignment between their lived experiences and the expectations of the scientific field. This misalignment of habitus leads some students to perceive scientific practices as inaccessible or overly rigid (Taasoobshirazi & Carr, 2008). Even when they understand the formal 'rules' of the practice, their lack of exposure to dominant norms may hinder meaningful engagement (Godec et al., 2018).

To counter these effects, pedagogy should be more inclusive of diverse epistemic practices. Erduran and Dagher (2014) argue that science education should present a 'diverse range of processes, products, and mechanisms of science' (p. 71) while ensuring that these concepts are presented coherently from the students' perspective. Bourdieu's insights extend this argument, emphasising the importance of addressing students' habitus and social background. Teachers should create learning environments where scientific practices are de-mystified and contextualised within broader social and historical frameworks. By highlighting how power structures shape the production and legitimisation of scientific knowledge, students from all social backgrounds can better connect with the scientific process. This approach involves encouraging students to reflect on the social and institutional forces that shape scientific inquiry. Students should be taught that the coherence of scientific practices, as presented in the classroom, is not an objective truth but a product of social processes. Deconstructing these norms allows students from marginalised backgrounds to see themselves as participants in the scientific enterprise. By creating an environment that recognises the interplay of habitus, field and capital, educators can foster more inclusive engagement in scientific practices and encourage a broader range of students to participate and succeed in science.

5.1.4 Knowledge: Structuralist Constructivism and the Legitimacy of Scientific Knowledge

Scientific knowledge is conceptualised as a dynamic, interconnected system comprising theories, laws and models (Erduran & Dagher, 2014). These elements work together to explain natural phenomena, and their classification reflects the methodological and epistemic diversity across scientific disciplines. For instance, scientific laws in physics differ from those in biology, underscoring the pluralistic nature of scientific knowledge. FRA emphasises explanatory pluralism, the coexistence of multiple explanations for the same phenomenon, as essential to understanding the nature of science. Erduran and Dagher (2014) argue that science education should move beyond presenting facts to exploring the processes and mechanisms that underlie knowledge production, encouraging students to reflect on how knowledge is created, classified and validated.

Bourdieu's sociological perspective adds a critical dimension to this understanding of knowledge by situating it within the broader social structures that shape its production, validation and dissemination (Sullivan, 2008). According to Bourdieu, scientific knowledge is not an objective depiction of reality but a form of symbolic capital—a resource that can be accumulated, exchanged and used to maintain power and prestige. Within the scientific field, power relations influence which knowledge is legitimised and which is marginalised.

Knowledge production is thus a competitive process where researchers seek to accumulate symbolic capital to bolster their status. The process of classifying and validating knowledge reflects the power dynamics of the field, often privileging the perspectives of dominant groups while excluding or devaluing knowledge from marginalised communities (Archer et al., 2015). This dynamic aligns with FRA's emphasis on the classification of scientific knowledge but adds a critical dimension, showing how social hierarchies shape perceptions of coherence and legitimacy.

Bourdieu's concept of habitus further reveals how social structures shape the production of scientific knowledge. Scientists' judgments about which theories, laws and models to prioritise are influenced by their habitus, which reflects their social position within the scientific field. Those with higher symbolic capital have greater influence, often reinforcing dominant paradigms while marginalising alternative perspectives. While FRA advocates for explanatory pluralism, Bourdieu highlights how dominant groups may suppress alternative frameworks that challenge established norms. His concept of the scientific field explains how knowledge is contested, validated and disseminated, with researchers competing for resources like funding, recognition and prestige. A researcher's position in this competitive field affects the acceptance of their contributions, shaping which knowledge is classified as legitimate. Educators play a critical role in helping students understand how scientific knowledge is socially constructed and linked to broader power structures. By fostering this awareness, students can critically engage with science and recognise how it reflects and reproduces social inequalities.

These power dynamics also play out in educational contexts, where students encounter the same processes of classification and legitimisation. Bourdieu highlights how symbolic violence (Bourdieu & Passeron, 1990) occurs in education when dominant cultural norms are presented as 'universal' or 'neutral'. In science education, symbolic violence manifests in the way certain forms of knowledge are privileged while others are dismissed. For instance, school curricula often emphasise the contributions of dominant social groups, such as Western, male-dominated scientific perspectives, while marginalising knowledge from underrepresented groups, including women and racial minorities. This marginalisation reinforces the idea that legitimate knowledge must conform to specific, dominant cultural standards. Mu (2021) and Archer et al. (2018b) argue that educators should challenge these power imbalances by encouraging students and parents to question how scientific knowledge is produced, validated and legitimised. Bourdieu's pedagogical insights urge educators to go beyond teaching 'objective' scientific content to critically engage with the cultural and social dimensions of knowledge production. He argues for a reflexive pedagogy that questions whose perspectives are legitimised and why certain views dominate. By exposing the social forces shaping scientific knowledge, educators can disrupt exclusionary practices. This perspective aligns with FRA's goal of engaging students in the processes of knowledge production but extends it by encouraging students to critically analyse how power, privilege and cultural dominance shape these processes.

5.2 Social-Institutional System

The social-institutional dimensions of NOS (Table 2) pertain to how scientific knowledge is certified, disseminated and influenced by broader societal forces, such as professional roles, financial systems and political power structures. Bourdieu's concepts of capital, field and habitus offer a critical lens for understanding how social institutions shape scientific practice. These concepts reveal how power dynamics, social hierarchies and economic interests influence whose knowledge is legitimised, whose contributions are amplified, and how these processes reinforce existing inequalities within the scientific community.

5.2.1 Social Certification and Dissemination: Authority in Knowledge Validation

The social certification of scientific knowledge—through peer review, publication and quality control—plays a crucial role in establishing its legitimacy. Bourdieu argues that scientific credibility is not solely based on objective merit but is also linked to the symbolic capital of the researchers and institutions involved. Scientists with higher symbolic capital, such as those at prestigious institutions or in influential positions, are more likely to have their work certified and disseminated as legitimate. The peer review process, often regarded as objective, is shaped by power dynamics in the scientific field (Sun et al., 2013). Senior researchers with significant symbolic capital serve as gatekeepers, determining the quality and validity of submissions. Their judgments can reinforce existing hierarchies, making it easier for established scientists to gain acceptance while subjecting junior or less connected researchers to greater scrutiny.

Beyond certification, the dissemination of scientific knowledge extends to media, public engagement and policy advocacy (Stilgoe et al., 2014). Scientific knowledge does not 'speak for itself' but must be actively promoted. Scientists with strong social capital—through networks with policymakers, journalists and public figures—are better positioned to amplify their findings in public discourse. Professional activities like publishing papers, attending conferences and engaging with media platforms enhance a scientist's visibility and influence. This dynamic underscores how symbolic capital enables scientists to shape public understanding of scientific issues.

Reforms to the peer review process aim to make certification more equitable. Open peer review, where reviewer identities are disclosed, fosters accountability (Tennant et al., 2017). Collaborative review models allow for public commentary, promoting transparency and inclusivity (Tennant, 2018). Further, diversifying reviewer pools, encouraging post-publication reviews and recognising non-traditional outputs (e.g. preprints) reduce the influence of entrenched hierarchies and create fairer opportunities for knowledge validation (Alperin et al., 2022). These changes aim to distribute symbolic capital more equitably and promote inclusivity in scientific certification.

Reforms to the peer review process aim to redistribute symbolic capital more equitably within the scientific field. Open peer review, intended to foster transparency (Tennant et al., 2017), may instead reinforce hierarchies, as elite affiliations confer implicit legitimacy, leading to preferential treatment (Ross-Hellauer, 2017), while less prestigious institutions face greater scrutiny (Bravo et al., 2019). Similarly, disclosing reviewer identities can introduce symbolic violence, discouraging junior scholars from critiquing senior academics due to career concerns (Hopp & Hoover, 2017). Collaborative review models promote inclusivity (Tennant, 2018) but risk amplifying dominant voices and marginalising alternative perspectives (Kovanis et al., 2016). To counteract these power asymmetries, reforms must disrupt rather than reproduce existing hierarchies. Structured moderation—such as anonymised contributions—can prevent epistemic monopolisation while preserving collective critique. Hybrid models like double-open review balance transparency with reviewer protection (Ford, 2015), while facilitated peer review ensures critiques remain constructive, limiting exclusionary dynamics (Smith, 2010). Beyond structural adjustments, shifting the habitus of peer review requires diversifying reviewer pools, legitimising post-publication review and recognising non-traditional outputs like preprints to challenge traditional

Table 2 The social-institutional of NOS: Wittgensteinian (Erduran & Dagher, 2014) vs. Bourdieusian (authors' elaborations) approaches to NOS and pedagogy

Categories	Definitions	Wittgensteinian lens	Wittgensteinian FRA to pedagogy	Bourdieusian lens	Bourdieusian-inspired approaches to pedagogy
Social Certification and Dissemination	Peer review and quality control of scientific work	Meanings are socially negotiated via peer review	Students engage in classroom validation processes, mimicking certification in science	Certification reinforces symbolic power, with elite scientists controlling validation processes to maintain dominance	Encourage students to critique power imbalances in knowledge validation and reflect on barriers faced by marginalised groups
Scientific Ethos	Norms such as scepticism and objectivity that scientists engage with	Norms of objectivity and scepticism emerge from shared language games	Students engage in inquiry and critique, mirroring scientific norms	Symbolic power affects how norms are applied; elites face less scrutiny, reinforcing inequality	Highlight how power influences the uneven application of norms like scepticism, encouraging students to challenge 'unquestioned' authority in science
Social values	Values agreed upon by society	Values like freedom and sustainability are continually negotiated within language games	Students learn how social values influence ethical choices in scientific practice	Power and symbolic capital shape the alignment of scientific priorities with dominant societal values	Use case studies to show how dominant values shape research priorities and highlight marginalised perspectives
Professional Activities	Activities like attending conferences and publishing papers	Scientists engage in social norms of presenting, publishing and evaluating work	Students participate in peer discussions, public sharing and feedback, mirroring professional practices	Symbolic and social capital shape access to publishing, conferences and networks, reinforcing hierarchies	Expose how access to professional opportunities is influenced by capital, and guide students in networking strategies to navigate these structures
Social Organisations and Interactions	Institutions, unions and research centres that influence scientific work	Expert status is socially negotiated through language games	Students explore institutional hierarchies and funding dynamics, understanding the roles of research centres and professional organisations	Institutions reproduce power hierarchies; those with aligned habitus and symbolic capital have greater access to opportunities	Highlight institutional norms and teach students strategies to navigate hierarchies, focusing on access for marginalised groups

Table 2 (continued)

Categories	Definitions	Wittgensteinian lens	Wittgensteinian FRA to pedagogy	Bourdieusian lens	Bourdieusian-inspired approaches to pedagogy
Financial Systems	Role of economics in scientific research and its impact on business	Knowledge is commodified through patents and market-driven research	Students explore how financial pressures affect knowledge production using case studies on patents and commercialisation	Economic capital drives funding, with research priorities aligned with funders' interests (profit-driven agendas)	Use case studies (e.g. pharmaceutical patents) to show how financial interests shape research priorities, encouraging students to critique market influence
Political Power Structures	Role of politics in influencing scientific work	Scientific knowledge reflects social and political contexts (e.g. colonialism, gender, militarisation)	Students analyse political influences on science and critique the 'value-free' narrative	Political capital shapes funding, research priorities and regulatory power	Teach students how political power structures shape research, encouraging critical engagement with science-policy intersections

gatekeeping (Alperin et al., 2022). Flexible peer review formats—allowing journals to choose between anonymous, open or hybrid models—can maintain disciplinary rigor. Formal training on bias mitigation and ethical critique (Steer & Ernst, 2021) can further foster equitable evaluation. Rather than merely redistributing symbolic capital, these reforms seek to transform the structures of scientific certification, promoting a more reflexive and inclusive peer review system.

5.2.2 Scientific Ethos: Norms, Power and Ethical Tensions

The scientific ethos—encompassing scepticism, rigor and objectivity—is deeply embedded in the social-institutional aspects of the nature of science (NOS). Bourdieu highlights that these norms are neither universal nor static but are shaped by power dynamics within the scientific field. Scientists internalise them as part of their habitus, yet their application varies based on social position. For instance, scepticism—a core principle of scientific inquiry—may be applied more leniently to senior researchers with high symbolic capital, whereas junior scholars or those from less prestigious institutions face greater scrutiny. This uneven distribution of authority reflects how symbolic capital influences which voices are heard and whose claims are rigorously evaluated. Bourdieu's concept of field further reveals how competitive pressures distort the scientific ethos. The publish or perish culture, driven by the accumulation of academic capital, can lead to the prioritisation of productivity over rigor, fostering questionable research practices (Fanelli, 2010; Tie & Wang, 2022). Hyper-competition intensifies research bias, particularly in academic systems where institutional pressures are extreme, such as in the U.S. (Fanelli, 2010) and China (Tie & Wang, 2022). These pressures shape the habitus of researchers, normalising strategic publication behaviours that may compromise ethical integrity.

Addressing these tensions requires institutional and epistemic shifts. Open science initiatives (Nosek et al., 2015) and diversified evaluation metrics (Teixeira da Silva, 2020) help decentre the dominance of publication quantity as a marker of scientific capital, allowing rigor and ethical practices to be prioritised. From a Wittgensteinian perspective, the norms governing scientific practice are embedded in language games—collective rule-following practices shaped by context. Reconfiguring these practices, such as redefining what counts as impactful research, can shift the rules of the game away from hyper-productivity toward sustainable and ethical scientific work. Institutional interventions—such as recognising methodological rigor, data sharing and collaborative research as valued contributions—can reshape the field by redistributing symbolic capital more equitably. Additionally, fostering reflexivity in scientific training can enable researchers to critically examine their position within these structures, reducing the unconscious reproduction of exclusionary norms. By integrating Bourdieu's critique of power with Wittgenstein's view of meaning-making in practice, a more balanced, ethical and inclusive scientific ethos can be cultivated—one that prioritises both knowledge production and the integrity of the scientific process.

5.2.3 Social Values: The Alignment of Science with Societal Expectations

Scientific research is deeply influenced by social values and expectations. Bourdieu's concept of symbolic capital explains how scientific institutions and individuals leverage their reputations to align with societal priorities, thereby enhancing the legitimacy and public acceptance of scientific knowledge. Research that addresses pressing societal issues, such as climate change or public health, is more likely to secure funding and public support.

Bourdieu's notion of reflexivity encourages scientists to critically examine the social impact of their work, moving beyond technical problem-solving to consider broader ethical implications (Bourdieu & Wacquant, 1992; Soedirgo & Glas, 2020). For example, the development of medical treatments or new technologies often raises ethical questions, prompting researchers to engage in responsible innovation. Recent studies have highlighted the importance of reflexivity across various disciplines. In sustainability science, a framework has been developed that positions reflexivity as a transformative capacity, encouraging scientists to reflect on their roles and assumptions to promote ethically sound and socially relevant research (Lazurko et al., 2025). Similarly, in conservation science, there is a growing recognition of how personal values and unidentified biases can influence research outcomes, emphasising the need for reflexivity to ensure that conservation efforts are both effective and ethically grounded (Kaechele et al., 2024). Moreover, in the realm of data science, the concept of 'computational reflexivity' has been introduced (Cambo & Gergle, 2022), involving data scientists reflecting on their methodological choices and the potential biases in their models. It encourages scientists to reflect on the (un)conscious alignment of their work with societal expectations, but meanwhile acknowledges the challenges of maintaining scientific autonomy and resisting external pressures that may compromise methodological rigor or ethical integrity. Reflexivity thus promotes a socially conscious approach to science, encouraging researchers to reflect on how their work shapes and is shaped by broader social, ethical and political contexts, fostering greater accountability and inclusivity in knowledge production.

5.2.4 Social Organisations and Interactions: Development of Habitus

Scientific institutions, such as universities and research centres, serve as social fields where agents (researchers, administrators, students) navigate hierarchical structures and power dynamics (Lemke, 2001). Within these institutions, individuals develop a habitus shaped by their experiences and position within the field. Bourdieu's concept of field illustrates how these institutions are stratified, with senior researchers and established scientists accumulating symbolic capital (prestige, authority, recognition) through academic titles, publications and leadership roles (Rowlands, 2018). This symbolic capital allows them to influence institutional priorities and access resources. Early-career researchers, by contrast, often have less social and symbolic capital, making it harder for them to feel integrated into institutional culture. Their habitus may not align with the competitive and individualistic norms of the scientific field, leading to feelings of alienation. Those whose habitus matches dominant norms—often individuals from privileged backgrounds—are more likely to succeed, while others face barriers to full participation. However, Bourdieu highlights that habitus is adaptable; through experience and familiarity with institutional norms, individuals can accumulate capital over time. This process, however, often requires them to internalise dominant values, which may create tensions with their pre-existing dispositions.

5.2.5 Professional Activities: The Accumulation of Social Capital in Science

Professional activities, such as attending conferences, publishing research and engaging in collaborative projects, are essential for scientists to accumulate social capital and advance within the scientific field. Bourdieu's theory highlights how these activities are embedded in networks of relationships and power structures that shape career trajectories. Well-connected scientists who collaborate with influential researchers or have access to prestigious dissemination platforms (like high-impact journals) are better positioned to build social capital and progress in their careers. Professional organisations and collaborative networks also play a key role in shaping the direction of scientific research and facilitating knowledge exchange. However, Bourdieu's framework reveals that these networks are not neutral. Senior scientists and those from prestigious institutions hold positions of authority within editorial boards, funding bodies and conference committees. Their access to greater economic capital (funding and institutional resources) further reinforces their influence within the field. Consequently, professional activities are not just about knowledge sharing but also about power negotiation. Scientists who can effectively navigate these professional networks accumulate symbolic capital, enhancing their ability to succeed in the competitive field of science.

5.2.6 Financial Systems: Economic Capital and the Commercialisation of Science

Economic capital plays a pivotal role in shaping scientific research. Bourdieu's framework highlights how funding agencies, philanthropic organisations and corporate partnerships influence the direction of research by controlling access to financial resources. To secure funding, scientists often align their research with the strategic interests of these financial bodies (Kleinman & Vallas, 2001). The commercialisation of science introduces additional complexities, as researchers seek patents and intellectual property rights, allowing them to transform discoveries into marketable products. Scientists with institutional support or private investment have a distinct advantage in navigating this commercial landscape, further reinforcing their position within the scientific field. However, Bourdieu underscores the potential conflict between commercial interests and scientific integrity. Corporate partnerships may steer research toward projects with immediate financial returns, sidelining long-term, socially valuable research. This tension requires scientists to balance the pursuit of knowledge with financial demands, all while maintaining their commitment to the ideals of scientific rigor and independence.

5.2.7 Political Power Structures: Navigating the Field of Power in Science

Bourdieu's concept of the field of power offers insights into how scientific institutions interact with political power structures. Scientific organisations operate within broader fields of power, where political entities influence research priorities, funding decisions and regulatory frameworks (Ivemark & Ambrose, 2021). Governmental bodies and political actors shape the allocation of research funding, especially in areas linked to national interests, such as public health and energy (Chan et al., 2023). Scientists with substantial cultural and social capital are often better positioned to leverage political networks, securing funding and influencing research agendas. For instance, scientists who serve as government advisors or maintain strong connections with policymakers are more likely to attract support for their projects. Additionally, regulatory frameworks established by political institutions influence scientific practices, from ethical guidelines to safety standards. Bourdieu's theory of symbolic power reveals how political actors shape these norms, often reflecting societal interests and power hierarchies. As a result, scientists must navigate a complex web of political relationships, balancing autonomy in research with compliance with regulatory and policy demands.

5.3 The Interaction Between Cognitive-Epistemic and Social-Institutional Systems

The interaction between cognitive-epistemic and social-institutional systems in science is dynamic and reciprocal. These systems do not function independently but instead influence one another, shaping both the practice and organisation of science. Bourdieu's concepts of habitus, capital and field provide a valuable framework for understanding how social and cultural factors impact scientific activities. This interaction reveals how the cognitive processes of science—like reasoning, theorising and experimentation—are intertwined with social structures, power relations and institutional norms.

5.3.1 The Scientific Field as a Site of Interaction

The scientific field serves as a key site where cognitive-epistemic and social-institutional systems converge. This field operates under its own set of norms, values and practices that govern scientific activities. Scientists and institutions within this field engage in the production, validation and dissemination of knowledge while navigating the influence of intellectual, social and institutional forces. The scientific field is governed by competition and collaboration, as scientists and institutions seek recognition, funding and influence. This logic affects the cognitive-epistemic processes, like theory development and methodological choices, and also shapes the social-institutional dynamics, including resource allocation, recognition and status within the community. Importantly, the scientific field is not isolated from other social fields, such as political, economic and cultural fields, which influence its operations. These broader societal forces shape the rules governing the distribution of opportunities, resources and prestige within the scientific field.

5.3.2 Habitus as the Medium of Interaction

Habitus functions as a bridge between cognitive-epistemic and social-institutional systems, shaping the norms, values and practices that define scientific activities. Scientists acquire a scientific habitus through education, training and professional experience, which influences their approach to research, including the development of hypotheses, choice of methodologies and interpretation of data. These cognitive-epistemic practices are not purely objective but are shaped by the social and cultural dispositions internalised by scientists. At the same time, habitus shapes the social-institutional dimensions of science. The practices internalised by scientists contribute to the organisational cultures, policies and norms of research institutions, regulatory bodies and funding agencies. For instance, early-career researchers with limited symbolic and social capital may struggle to navigate the competitive and hierarchical structures of scientific institutions. Habitus, therefore, bridges individual cognitive-epistemic processes with broader social-institutional practices, enabling scientists to operate within the field while also influencing its structure over time.

5.3.3 Capital as the Power Resource for Interaction

Capital—economic, cultural, social and symbolic—acts as a key power resource in the interaction between cognitive-epistemic and social-institutional systems.

- Economic capital: funding, financial support and institutional resources enable the pursuit of ambitious research projects, acquisition of cutting-edge technologies and execution of large-scale experiments. Access to this capital influences both the scope of scientific inquiry (cognitive-epistemic) and the structure of scientific institutions (social-institutional).

- Cultural capital: represented by scientific expertise, academic qualifications and methodological competencies, cultural capital shapes the authority and credibility of scientists. It influences which scientists are viewed as credible voices in their field and determines how their research is received and disseminated.
- Social capital: relationships, networks and collaborations facilitate access to research opportunities, intellectual resources and strategic partnerships. Social capital enhances both cognitive-epistemic processes, such as the co-creation of knowledge and social-institutional dynamics, like collaboration on grant applications or participation in policy advocacy.
- Symbolic capital: prestige, recognition and authority enable scientists and institutions to wield influence within the scientific field and beyond. Those with high symbolic capital (e.g. recipients of major awards or high-profile grants) are more likely to have their research legitimised, funded and disseminated. Symbolic capital reinforces power hierarchies in the field, affecting who gets published, promoted and recognised within the scientific community.

Together, these forms of capital shape the interdependence of cognitive-epistemic processes and social-institutional structures. Access to these forms of capital influences the production, validation and dissemination of scientific knowledge, underscoring the social nature of cognitive-epistemic processes in science.

5.4 Implications to Science Education

Bourdieu's framework highlights the significance of power dynamics and reflexivity in science education. Power shapes how scientific knowledge is produced, valued and accessed, influencing students' learning experiences and access to educational resources. Reflexivity involves critically examining assumptions and biases, allowing educators and students to challenge dominant narratives and foster more equitable learning environments. Bourdieusian-inspired pedagogical approaches, as summarised in Table 1 and Table 2, offer inclusive and reflective teaching practices guided by three core principles.

5.4.1 Recognising Power Dynamics in Science Education

Power dynamics in science education manifest through the privileging of specific knowledge forms, the authority of experts and the influence of institutional structures. Scientific knowledge is often seen as objective and authoritative, reinforcing the dominance of certain perspectives while marginalising alternative views. By recognising these power dynamics, educators can promote a more inclusive, pluralistic understanding of science. This includes valuing multiple knowledge systems, such as Indigenous ecological knowledge, within science curricula. Such an approach allows students to see science as a diverse, contested and evolving field.

Institutions further shape power dynamics by controlling curricula, assessments and access to resources. These structures tend to reinforce existing hierarchies, privileging certain groups while sidelining others. By critically examining these structures, educators can identify and address barriers to inclusion. Applying Bourdieu's lens, it becomes clear that symbolic capital—such as prestigious academic qualifications and scientific recognition—must be redistributed to create more equitable learning spaces (Archer et al., 2024). This redistribution is especially important for marginalised students, whose knowledge, identities and experiences have historically been undervalued in science education. For instance, assignments that highlight the contributions of underrepresented groups, case studies on the lived experiences of students and reflexive journaling on power dynamics in science promote critical thinking and student engagement. These activities foster higher-order reasoning and challenge dominant narratives, ultimately supporting more inclusive forms of scientific inquiry. Through these efforts, students gain access to symbolic capital, enhancing their academic and professional prospects.

The classroom reflects the broader field of science education, with ongoing negotiations of power and authority (Reinsvold & Cochran, 2012). Both teachers and students navigate a space where access to resources, recognition and influence is unevenly distributed. A Bourdieusian approach calls on educators to recognise and value the cultural and social capital that students bring with them. One of the challenges in addressing power structures in classrooms is the distinction between cultural and scientific knowledge. Cultural knowledge, which is often context-specific and rooted in community experiences, may be embraced in certain lessons (e.g. citizen science knowledge in environmental science) but overlooked in others (e.g. physics). Scientific knowledge, on the other hand, is seen as cross-cultural and grounded in systematic evidence. Acknowledging both forms of knowledge allows educators to create more inclusive classrooms (Erduran et al., 2020). For example, integrating community-based knowledge into the curriculum helps students see the relevance of their experiences to scientific inquiry, thereby bridging the gap between local knowledge and the broader scientific enterprise. By acknowledging the diverse knowledge systems and lived experiences of students, teachers can create learning environments where all students feel valued. This addresses classroom hierarchies and valuing all forms of capital, educators can foster more inclusive learning environments. Redistributing symbolic capital—such as access to key learning tools, recognition of diverse perspectives and an appreciation of community-based knowledge—can empower students from marginalised communities (Archer et al., 2024). This shift not only enhances student engagement but also broadens the epistemic scope of science education, fostering a more diverse and participatory field of inquiry.

5.4.2 Integrating Reflexivity in Science Education

The interaction between cognitive-epistemic and social-institutional systems fosters reflexivity in both scientists and science learners. Reflexivity, a key concept in Bourdieu's and Wittgenstein's frameworks, calls for critical self-examination of one's assumptions, biases and positionality. Bourdieu's reflexive sociology urges researchers to scrutinise their social positions and biases (Bourdieu & Wacquant, 1992), while Wittgenstein's philosophy emphasises the need for self-awareness and the recognition of the limitations of language (Peters, 2000). Together, these perspectives stress the importance of self-awareness in teaching and learning (Bohman, 1997; Burkitt, 1997; Heilbron, 1999; Kögler, 1997; Ortiz, 2022).

In science education, reflexivity requires educators to consider their own assumptions about knowledge, pedagogy and social positions. It encourages them to question the values embedded in curricula and recognise how habitus—the ingrained dispositions shaped by social experiences—affects cognitive biases and scientific perspectives. Reflexive educators foster critical inquiry, enabling students to challenge dominant paradigms and explore alternative perspectives (Klaver et al., 2023). Reflexivity moves beyond the inclusion of everyday experiences in science lessons; it calls for a deeper interrogation of the power dynamics within classrooms and the broader societal context (Archer et al., 2018a, 2018b).

A Bourdieusian approach to reflexivity allows educators to challenge dominant narratives that privilege certain knowledge systems while marginalising others (Kenway & McLeod, 2004). By critically examining these narratives, educators promote inclusivity and equity, making space for diverse cultural and epistemic perspectives. This shift towards culturally responsive teaching incorporates students' social and cultural backgrounds into science education, creating a richer array of perspectives and understandings. Such approaches help students see themselves as active contributors to scientific knowledge rather than passive recipients. Reflexivity also empowers students to think critically and engage with the scientific process as active agents (Hibbert, 2013). By encouraging them to question assumptions, challenge existing power structures and interrogate social norms, reflexive education allows students to see science as a participatory and evolving process. Bourdieu's analysis of pedagogy reveals that traditional education tends to reproduce the values and culture of dominant groups, encouraging students to 'know their place' within existing social orders (Archer et al., 2024; Bourdieu & Passeron, 1990). Reflexive education, by contrast, disrupts this cycle. It empowers both students and educators to recognise and challenge these social norms, paving the way for a more democratic and transformative science education.

5.4.3 Promoting Inclusivity Through Bourdieusian-Inspired Pedagogy

Bourdieu's framework underscores the need to address social inequalities within educational institutions to foster inclusivity in science education (Mills & Gale, 2007). His concepts reveal how educational spaces, such as classrooms and research centres, mirror broader social hierarchies that affect students' access to opportunities, recognition of their abilities and engagement with scientific inquiry. These hierarchies privilege certain forms of cultural and social capital, such as familiarity with academic language and competitive research practices (Archer et al., 2015). Students from privileged backgrounds often possess a habitus aligned with these institutional norms, giving them an advantage in navigating the scientific field (Khan, 2011). In contrast, students from underrepresented or marginalised groups may experience a misalignment between their habitus and the dominant expectations of science education, leaving them feeling 'out of place' (Bourdieu, 2018). This disconnection can hinder their participation and limit their potential for success.

To address these disparities, Bourdieu's theory calls for the recognition and validation of diverse forms of capital (Godec et al., 2018). Educators play a pivotal role in this process by acknowledging the varied cultural, social and experiential capital that students bring into the classroom. A Bourdieusian-inspired pedagogy seeks to dismantle rigid hierarchies by validating these diverse contributions and creating inclusive learning environments. This approach requires educators to reflect on their own biases and critically assess how power dynamics shape their teaching practices. By doing so, teachers can avoid inadvertently reproducing social inequalities and instead create spaces where students from all backgrounds feel empowered to engage with science (Archer et al., 2024). Another essential strategy for promoting inclusivity is the explicit teaching of institutional norms and the 'rules of the game' that govern scientific fields. Students from marginalised groups often face barriers, not due to a lack of ability, but because they are unfamiliar with the unspoken expectations of scientific practice. By demystifying these norms, educators can provide students with the knowledge and skills necessary to navigate the scientific field successfully, regardless of their background. This transparency helps level the playing field, offering marginalised students the same opportunities for success as their more privileged peers.

In addition to making institutional norms explicit, teachers should also encourage critical engagement with them. Rather than socialising students into existing structures, educators can guide students to question how these structures perpetuate inequalities. Classroom discussions might explore how certain research agendas or methodologies are prioritised over others, reflecting broader societal inequalities. This reflexive and critical approach empowers students to challenge the status quo and envision more inclusive forms of scientific practice. Pedagogical strategies that support inclusivity (Cunningham & Helms, 1998) may also include collaborative learning, mentorship and peer support. These approaches allow students from diverse backgrounds to share experiences and perspectives, fostering a sense of belonging and community. Such strategies reduce feelings of isolation and help students see themselves as part of the scientific community. Real-world case studies showcasing the contributions of scientists from diverse cultural and social backgrounds can further inspire marginalised students by allowing them to see themselves reflected in the scientific field (Berntsen et al., 2023).

6 Conclusions

This paper extends the notion of fluid boundaries between cognitive-epistemic and social-institutional systems, as articulated in Erduran and Dagher's (2014) FRA-NOS model, by incorporating Bourdieu's sociological insights. It begins by exploring the philosophical compatibility between Bourdieu and Wittgenstein, addressing critiques and highlighting their shared focus on the evolving nature of social practices. The analysis shows how Bourdieu's concepts of fields, capital and habitus enhance understanding of FRA-NOS, illustrating how science and science education are shaped by broader social structures and power dynamics. By viewing scientific knowledge as embedded within social contexts, this paper reveals how cultural norms, institutional practices and power hierarchies influence cognitive-epistemic dimensions, while these dimensions simultaneously shape the social world in which they operate.

Recognising power dynamics in science education is essential for understanding the processes of knowledge production and dissemination. Reflexivity emerges as a critical starting point, aligning with Dagher and Erduran's (2023) synthesis of the FRA-NOS model's philosophical and practical applications. Teachers must challenge symbolic violence—the marginalisation of particular forms of knowledge and identities—while valuing the diverse habitus and capital of all students (Archer et al., 2024). Prioritising inclusion requires recognising and addressing the exclusion of students whose knowledge, identities and lived experiences have been traditionally marginalised. This approach promotes equitable access to science education and a more critical understanding of scientific knowledge (Erduran et al., 2020).

Finally, this paper advocates for equipping students with both the technical tools to navigate the scientific field and the reflexive skills necessary to become critical thinkers (McLaren, 2023). Reflexivity enables students to critically assess the knowledge they acquire, recognise how social forces shape scientific inquiry and contribute meaningfully to discussions on science's role in society. By integrating Bourdieu's concepts into NOS in science education, we aim to foster a more inclusive, reflexive and socially aware approach to teaching and learning about science.

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Declarations

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